PB82-239369

Atmospheric Turbidity over the United States from 1967-1976

Washington State Univ.
Pullman

Prepared for

Environmental Sciences Research Lab.
Research Triangle Park, NC

Jul 82

U.S. Department of Commerce
National Technical Information Service
NTIS

PB82-239369

EPA 600/3-82-076
July 1982

ATMOSPHERIC TURBIDITY OVER THE UNITED STATES FROM 1967-1976

by

Elmer Robinson
Ralph J. Valente
Air Pollution Research Section
Chemical Engineering Department
Washington State University
Pullman, Washington 99164

EPA Grant No. 806124010

Project Officer

Herbert Viebrock
Meteorology and Assessment Division
Environmental Sciences Research Laboratory
Research Triangle Park, North Carolina 27711

ENVIRONMENTAL SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO. PB82-239369
4. TITLE AND SUBTITLE ATMOSPHERIC TURBIDITY OVER THE UNITED STATES FROM 1967-1976		5. REPORT DATE 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Elmer Robinson and Ralph J. Valente		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Washington State University Department of Chemical Engineering Pullman, WA 99163		10. PROGRAM ELEMENT NO. CDTA1D/03-0341 (FY-82) 11. CONTRACT/GRANT NO. R-806124-01-0
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Sciences Research Laboratory - RTP, NC Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, North Carolina 27711		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE EPA/600/09
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

Geographical, seasonal and long term variations in turbidity for the period 1967-1976 from the EPA/NOAA turbidity network are described. A model relating atmospheric turbidity to relative urbanization is also presented.

The 1967-1976 data show that increases in annual average nonurban turbidity since the first five years of turbidity monitoring (1961-1966) are primarily found over the southeastern United States with increases of about 30%. During 1967-1976 annual average turbidity increases primarily at stations in the Southeast. This increase is due mostly to increasing summer turbidity.

The model which is developed involves the separation of annual average urban turbidity into background and local effects terms where local effects are related to the local urban area population. This is a basis for estimating annual average turbidity at urban sites and for predicting long term changes. The correlation between model predicted values and actual monitoring data is shown to be good.

Patterns of regional turbidity were developed for the period June 25-July 5, 1975 to coincide with a low visibility pollution episode, but the turbidity data were too sparse to define the episode independent of the more detailed visibility pattern.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	106
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

NOTICE

Mention of trade names or commercial products does not consititute endorsement or recommendation for use.

ABSTRACT

Atmospheric turbidity, one of several measures of the impact of airborne particles on the optical quality of the atmosphere, has been measured in the United States with the Volz sunphotometer since 1960 in the joint EPA/NOAA turbidity monitoring network. This paper describes geographical, seasonal and long term variations in climatological turbidity for the period 1967-1976; and presents a new model, regionally stratified according to background levels, relating atmospheric turbidity to relative urbanization.

Results indicate that since the first five years of turbidity monitoring (1961-1966), the 1967-1976 data show that increases in annual average nonurban turbidity are primarily found over the southeastern United States. These changes are most noticeable in the summer season values and little or no time trend is shown in winter data.

The simple model which is described involves the separation of annual average urban turbidity for the monitoring sites into two terms representing background and local effects where local effects are related to the population of the local urban area. This technique provides a basis for estimating annual average turbidity at sites where no monitoring data are available and for predicting long term changes in annual average atmospheric turbidity. The correlation between model predicted values and actual monitoring data is shown to be good.

Patterns of regional turbidity were developed for the period June 25-July 5, 1975 to coincide with a heavy haze incident that had been examined as a low visibility episode. Although some qualitative correlation could be seen between the visibility and turbidity patterns the turbidity data were too sparse to define the episode independently. This feature of the turbidity data was a characteristic problem in attempting to evaluate regional turbidity episodes.

CONTENTS

Abstract iii

Figures vi

Tables viii

Acknowledgements ix

1. Introduction 1

2. Turbidity Observations 2

3. Research Techniques and Results 6
   The Atmospheric Turbidity Data Base 6
   Criteria for Climatological Analysis. 6
   Annual Average Background Turbidity 7
   Turbidity Time Trends During the 1967-76 Period . 19
   Discussion of Turbidity Trends 31
4. Model Relating Turbidity to Urbanization 33
   Derivation of Long-Term Model 33
   Model Assumptions and Limitations 36
5. Regional Studies 39
   Introduction 39
   Turbidity in a Slow Moving Anticyclone 39
   Discussion 41
6. Summary 45

References 46

Appendices

A. Detailed Presentation of the Turbidity Coefficient and its Calculation 49
B. Summary of Data For Regionally Stratified Model 56
C. Tabulation of Turbidity Annual Averages and Seasonal Averages by years - 1967-1976, United States Turbidity Network Stations 60

Preceding page blank

FIGURES

Number		Page
1.	Volz sun photometer	3
2.	Annual average background turbidity, 1967-1976	9
3.	Annual average background turbidity, 1961-1966, (after Flowers, et al. 1969)	10
4.	Change in annual average background turbidity since 1963	12
5.	Winter average background turbidity, 1967-1976	14
6.	Spring average background turbidity, 1967-1976	15
7.	Summer average background turbidity, 1967-1976	16
8.	Fall average background turbidity, 1967-1976	17
9.	Amplitude of the annual cycle in seasonal average turbidity.	18
10.	Seasonal and annual trends in mean turbidity at Greensboro, NC	20
11.	Seasonal and annual trends in mean turbidity at Oak Ridge, TN	21
12.	Seasonal and annual trends in mean turbidity at Meridian, MS	22
13.	Seasonal and annual trends in mean turbidity at Little Rock, AR	26
14.	Seasonal and annual trends in mean turbidity at New York, NY.	27
15.	Seasonal and annual trends in mean turbidity at Green Bay, WI	28
16.	Seasonal and annual trends in mean turbidity at Huron, SD	29
17.	Seasonal and annual trends in mean turbidity at St. Cloud, MN	30

Number Page

18. Seasonal and annual trends in mean turbidity at Missoula, MT. 32

19. Excess turbidity vs. population at network sites 35

20. Model predicted turbidity compared to measured values. 37

A-1. Beer's law transmission of the direct beam at 500 nm 50

A-2. Geometry of optical air mass. 52

TABLES

Number		Page
1.	Turbidity monitoring stations in the continental United States	4
2.	Background sites for climatological analysis (1967-1976)	8
3.	Linear regression equations for seasonal and annual average turbidity trends at selected sites for 1967 to 1976	23
4.	Daily turbidity coefficient observations during an air pollution episode - June 25 to July 5, 1975	42

ACKNOWLEDGMENTS

This research work was aided significantly by the assistance of Drs. Edwin Flowers, James Peterson, and Rudi Haas, Air Resources Laboratories, NOAA, Boulder, Colorado. We gratefully acknowledge their help in accumulating data files and interpreting computer tape records. Mr. W. Lee Bamesberger, WSU Chemical Engineering Department was instrumental in setting up the WSU computer operations for our data analysis.

SECTION 1

INTRODUCTION

Air pollutants when dispersed in the atmosphere can change the optical properties of the atmosphere. These changes may occur due to increased absorption and scattering effects resulting from both pollutant gases and particles. Common atmospheric optical properties are the visibility which usually implies an optical path parallel to the earth's surface and the turbidity which is most commonly related to a change in solar intensity and thus to a more or less vertical sight path. Actually, by definition, turbidity in the meteorological context is "any condition of the atmosphere which reduces its transparency to radiation, especially to visible radiation" (Huschke, 1959). In a quantitative manner a turbidity coefficient can be calculated from solar intensity measurements. The calculation procedure of Volz (1959) is used in this report and will be described in a subsequent section.

The importance of turbidity is demonstrated by the fact that on hazy days reductions in total irradiance at the surface can be of considerable magnitude. For example, McCree and Keener (1974) found a 20% reduction in total spectral irradiance at the surface (direct + diffuse) on a hazy day as compared to a clear day in Texas. Their data also showed a 50% reduction in the direct spectral irradiance with an attendant increase in diffuse irradiance. These figures do not represent the maximum impact of atmospheric turbidity on incoming solar radiation, however. Episodes of high turbidity in the eastern U. S. have produced conditions in which as much as 85% of the incoming solar radiation appeared as diffuse skylight (WMO et al., 1976). This compares to a "clean" atmosphere in which approximately 10-15% of the incoming radiation appears as skylight.

This present report is an analysis of atmospheric turbidity over the U. S. from 1967-1976 based on data from the EPA/NOAA turbidity network. Geographical, climatological, and temporal variations in turbidity are discussed and a simple, regionally stratified model relating long-term changes in atmospheric turbidity to changes in relative urbanization is described. This study is an extension of the report by Flowers et al. (1969) which presented an analysis of the turbidity network data for 1961-1966, the initial period of its operation.

SECTION 2

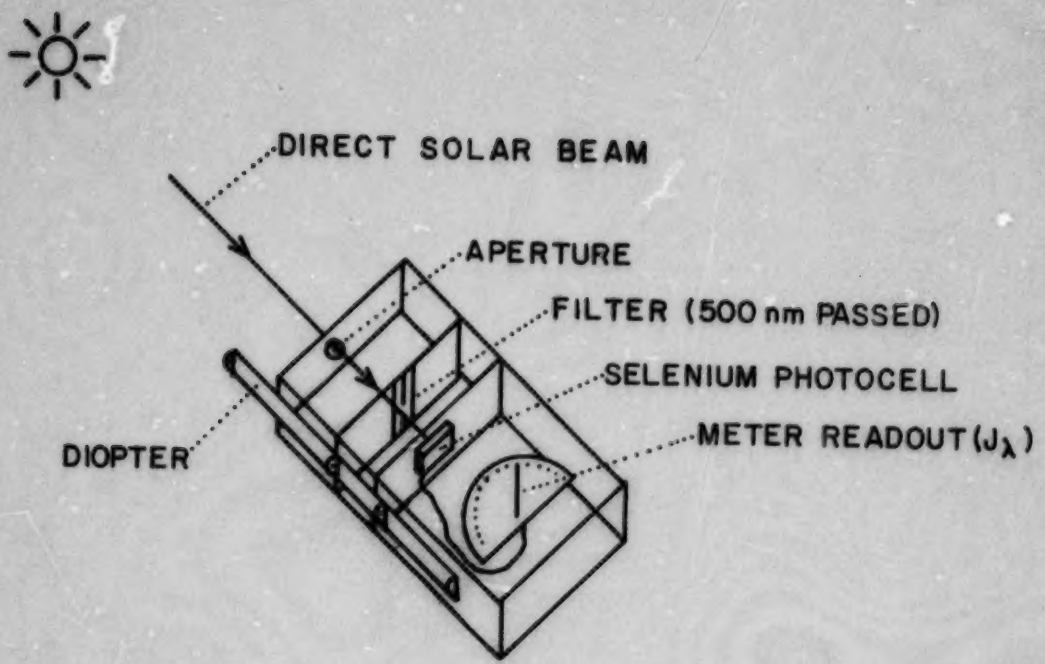
TURBIDITY OBSERVATIONS

The data for this study have been obtained from the files of the turbidity observation network set up in the United States in 1960-61 and operated since then as a cooperative EPA/NOAA program. Since 1971 the United States turbidity network has operated as part of a global program guided by the World Meteorological Organization (WMO). The basic instrument used in this turbidity program is the Volz sunphotometer. The Volz sunphotometer as illustrated by Figure 1, is sighted on the sun using a diopter. This allows the direct solar beam to enter through the aperture, pass through the filter and impinge on the photocell. The microammeter readout (J_λ) is proportional to the monochromatic intensity (I_λ).

The results of the initial 5 years of operation of the United States network, e. g., 1961-1966, have been described by Flowers et al., (1969). This report continues the analysis of turbidity data and covers the period 1967 to 1976. Since 1966 the size of the network has ranged from 25 to 40 stations. Table 1 lists the stations which have participated in the network since 1966 and the number of years during which data were collected from 1967 to 1976. A tabulation of yearly and seasonal average turbidity data for all network stations is given in Appendix C.

Flowers et al. (1969) describes the Volz photometers used in the network in considerable detail. Both Peterson et al. (1981) and Flowers et al. (1969) describe the accuracy of the Volz turbidity photometers in terms of calibrations against standard photometers. In comparison readings using the field-type sun photometers and a laboratory-maintained standard photometer the two types were found generally to agree within ±5% for higher values of turbidity, 0.100 and above, and within ±10% for lower values of turbidity, values near 0.040. Flowers et al. (1969) state that network field readings are probably less accurate than these laboratory results, but specific data were not available. Since the initiation of the turbidity network there have been a number of different evaluations of the Volz photometer and the turbidity measurement. Peterson et al. (1981) list a number of the published studies in which the accuracy of the photometer has been assessed.

In the present study as well as other references to turbidity network data the calculations refer to the turbidity at a wavelength of 500 nm because of the design and operation of the Volz photometer. Had a different wavelength been chosen different numerical values for the turbidity would have resulted from the calculations. Angstrom (1961, 1963) describes the turbidity concept and its calculation in considerable detail.



VOLZ SUNPHOTOMETER

Figure 1. Volz sunphotometer (single wavelength version).

TABLE 1. Turbidity monitoring stations in the continental United States (1967-1976).

Station	Number of Years Data Collected	Station	Number of Years Data Collected
Mount Hopkins, AZ	8	Ann Arbor, MI	1
Tucson, AZ	2	Saint Cloud, MN	10
Little Rock, AR	10	Meridian, MS	10
Albany Hill, CA	3	Kansas City, MO	1
Bishop, CA	5	Saint Louis, MO	8
Edwards Air Force Base, CA	3	Missoula, MT	10
Goleta, CA	2	Atlantic City, NJ	5
Los Angeles, CA	1	Albuquerque, NM	5
Pasadena, CA	1	Los Alamos, NM	9
Pittsburg, CA	4	Albany, NY	10
Port Chicago, CA	3	New York, NY	10
Redwood City, CA	5	Upton, NY	10
Richmond, CA	5	Whiteface Mt., NY	1
San Bernardino, CA	5	Asheville, NC	5
San Francisco, CA	5	Greensboro, NC	10
San Jose, CA	6	Raleigh, NC	8
San Rafael, CA	3	Bismarck, ND	4
Alamosa, CO	5	Columbus, OH	2
Boulder, CO	9	Cincinnati, OH	3
Denver, CO	2	Toledo, OH	10
Washington, DC	5	Youngstown, OH	10
Gainesville, FL	4	Pendleton, OR	5
Miami, FL	6	Philadelphia, PA	5
Tallahassee, FL	4	Huron, SD	10
Atlanta, GA	2	Memphis, TN	10
Idaho Falls, ID	7	Oak Ridge, TN	10
Chicago, IL	4	Grand Prairie, TX	6
Salem, IL	5	Victoria, TX	5
Topeka, KS	10	Houston, TX	2
Caribou, ME	5	College Station, TX	2
Baltimore, MD	10	Sterling, VA	2
Beltsville, MD	9	Redmond, WA	1
College Park, MD	8	Seattle, WA	3
Salem, IL	5	Elkins, WV	9
Blue Hill, MA	10	Green Bay, WI	10

In this study, as in those of Flowers et al. (1969) and Peterson et al. (1981) the turbidity coefficient, B, is based on the developments of Volz (1959). In this procedure B is the decadic extinction coefficient at 500 nm wavelength as defined by the expression

$$J/J_o = 10^{-(R + Z + B)m}$$

where J = the observed solar radiation at 500 nm adjusted to the mean sun-earth distance

J_o = the solar radiation outside the earth's atmosphere at the mean sun-earth distance

R = the Rayleigh scattering coefficient for the air molecules

Z = the gaseous absorption coefficient at 500 nm for ozone

B = the decadic turbidity coefficient

m = the optical air mass

In this equation and for 500 nm wavelengths the Rayleigh coefficient R has a value of 0.063 at sea level and for an air mass of m = 1 while the ozone absorption coefficient Z has a value of 0.05 (Eltermann, 1964; Peterson et al., 1981). The decadic turbidity B could be written as B_{500} to indicate the applicable 500 nm wavelength. However, since all values used in this present report apply to 500 nm this extra complication will be omitted. Appendix A to this report presents a more detailed discussion of the development of the turbidity coefficient and also gives a sample calculation applicable to the data from the turbidity network.

SECTION 3

RESEARCH TECHNIQUES AND RESULTS

THE ATMOSPHERIC TURBIDITY DATA BASE

The data base for this study was developed from magnetic tape and hard copy versions of the raw data from the U.S. atmospheric turbidity monitoring network. These were obtained either directly from EPA (see: U.S. Dept. HEW, 1967-1970) or from published network reports (see: WMO-EPA-NOAA, 1971-1976). For the turbidity climatological analysis, a comprehensive data set consisting of monthly average B values and the associated number of observations for the period 1967 to 1976 was prepared for all monitoring sites from the available source material.

CRITERIA FOR CLIMATOLOGICAL ANALYSIS

The nature of the turbidity measurement and the seasonal cycle in turbidity present obstacles to climatological averaging. Since the measurement can be made only when there is an unobstructed line of sight to the sun (i.e., no clouds blocking the direct beam) the number of observations varies from station to station and from season to season as well as with prevailing synoptic weather. The techniques discussed below were developed to minimize the potential for bias in the seasonal and annual average values which could be caused by these observing or sampling problems.

Trial calculations indicated that since the annual cycle is less noticeable within each season, seasonal average turbidities could be computed and used as an unweighted average of all the observations for the season without producing a significant bias toward periods of high or low turbidity. However, this could not compensate for the fact that all turbidity averages tend to be biased toward clearer weather due to the nature of the measurement. It should also be noted that if all observations for the spring or fall season in a given year are close to the beginning or the end of the season the calculated seasonal average may be some what higher or lower than seasonal averages calculated during years with more complete data records or data distributed uniformly through the season. For this study, seasons are defined in the conventional manner as: winter (December, January and February), spring (March, April and May), summer (June, July and August) and fall (September, October and November). The winter of 1978, for example, includes December 1977, January 1978 and February 1978.

In the annual averages each month is given equal weight even though the number of observations varies from month to month. This definition ensures that the annual averages will not be biased toward turbidities

associated with months when more observations are made due to fewer cloudy days.

The FORTRAN programs developed for this study calculated climatological average turbidities, as defined above, for all sites and observations. These are given as yearly and seasonal averages in Appendix C. Additional selection criteria were established as requirements for data adequacy before computer tabulated values were included in the trend analyses and model development. Specifically, stations were required to have at least 3 years of data, seasonal averages were required to have a minimum of ten observations, and annual averages were required to contain observations during at least ten months out of the year as well as a minimum of ten observations per season. These data criteria were chosen to reduce the variance of long term averages due to periods of sparse data, while discarding a minimum number of data points. These criteria were considered to be generally reasonable minimum limits. They were not subjected to objective statistical evaluations.

ANNUAL AVERAGE BACKGROUND TURBIDITY

The turbidity monitoring network stations as listed in Table 1 can be classed as urban and nonurban stations. By a review of station locations we classed as urban stations those located at sites where they would be influenced by cities of over 100,000 population. Sites in much smaller population centers, e.g. Pendleton, Oregon, or rural areas were considered as nonurban stations. In general the stations were classified similarly to that given by Flowers, et al. (1969) in their analysis of the 1961-66 network data. In the present assessment we are most concerned with nonurban or background turbidity. Thus in this report our use of the term "Background Turbidity" refers to observations which we believe are unaffected by nearby urban areas larger than 100,000 population. The background sites used in our program are listed in Table 2.

Our examination of turbidity began with an examination of the average background data, and Figure 2 shows the annual average background turbidity over the U.S. for the period 1967 to 1976. Individual values range from about 0.04 to 0.17. It should be noted that values for most cities with populations of 100,000 or more are significantly higher than these background levels. The effect of large cities on turbidity is examined in the modeling study described in a subsequent section.

For comparison, between the 1967-76 and the earlier 1961-66 period, the average annual background pattern of Flowers et al. (1969) is shown by Figure 3. Although there have been some changes in the magnitude of the annual average background turbidity, especially in the Southeastern United States, since Flowers made his earlier analysis, there are obvious similarities in the 2 sets of data.

The annual average turbidity pattern of Figure 2 shows significant differences between eastern and western regions. The highest annual average turbidities occur in the southern Appalachian and Smoky Mountain regions and thus is similar to the results of Flowers et al. (1969) for the

TABLE 2. Background sites for climatological analysis (1967-1976).

Station	Station
Mount Hopkins, AZ	Meridian, MS
Bishop, CA	Missoula, MT
Edwards Air Force Base, CA	Los Alamos, NM
Pittsburg, CA	Upton, NY
Alamosa, CO	Asheville, NC
Boulder, CO	Bismarck, ND
Gainesville, FL	Cincinnati, OH (suburban site)
Tallahassee, FL	Pendleton, OR
Idaho Falls, ID	Huron, SD
Caribou, ME	Oak Ridge, TN
Beltsville, MD	Victoria, TX
Blue Hill, MA	Elkins, WV
Saint Cloud, MN	Green Bay, WI

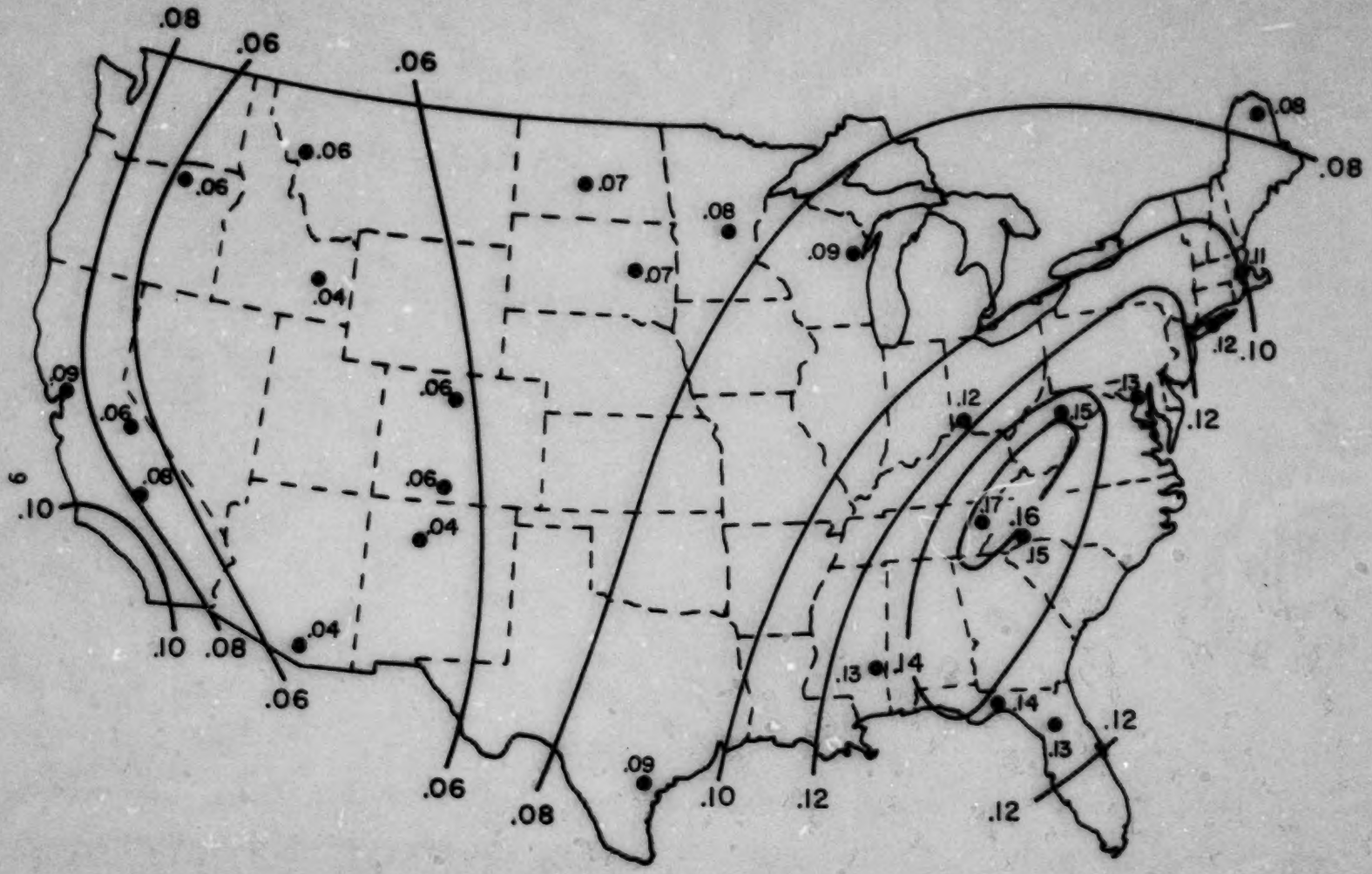


Figure 2. Annual average background turbidity, 1967-1976.

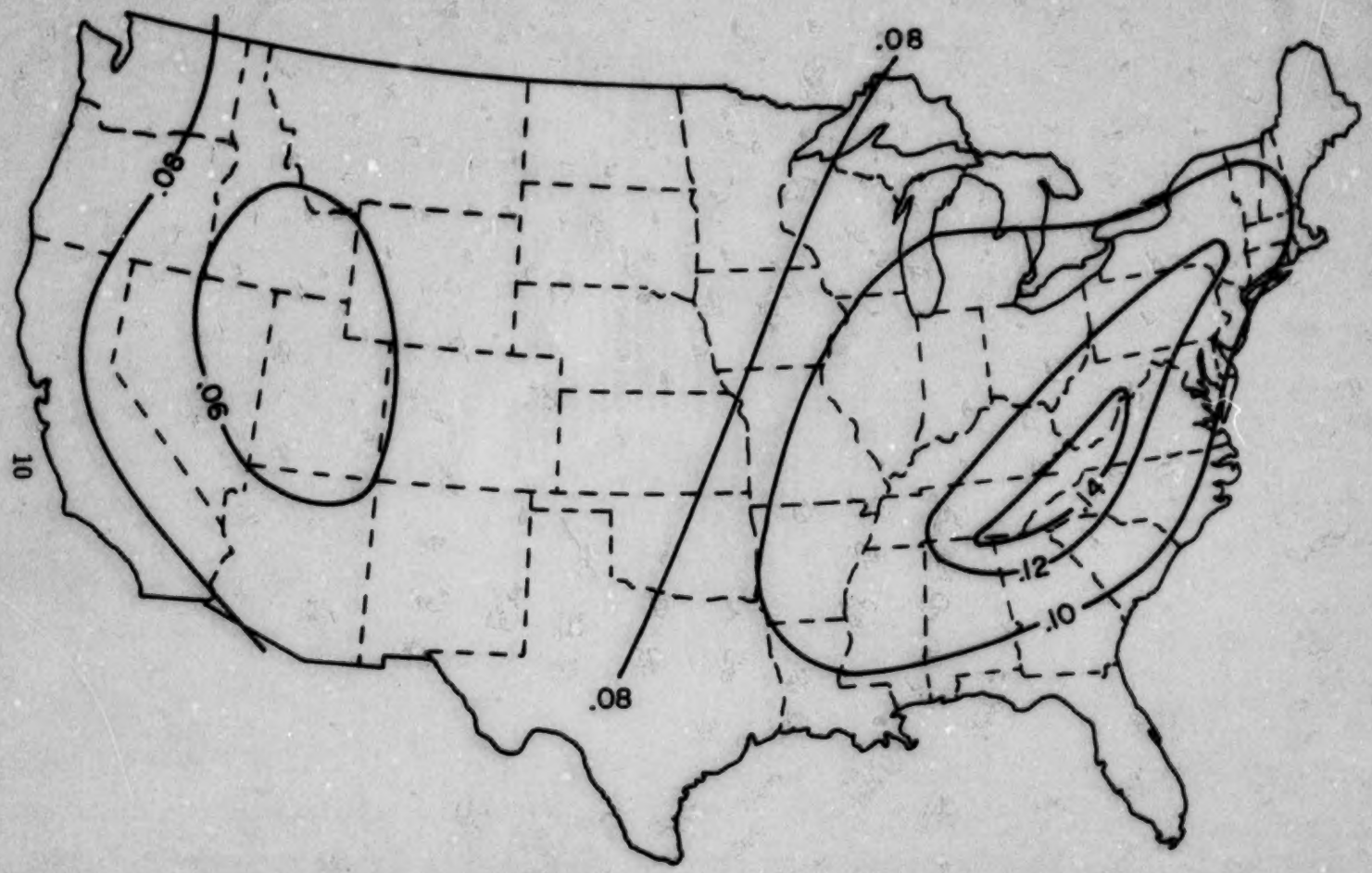


Figure 3. Annual average background turbidity, 1961-1966 (Flowers, et al. 1969)

1961-66 period shown in Figure 3. In the west the minimum average turbidity values are in the interior basin region generally defined on the east by the crest of the Rockies and on the west by the High Sierra and Cascade ranges. An increase since 1966 in the number of western stations makes it possible to draw a somewhat more detailed pattern in this area than was possible for Flowers and his colleagues. The flow of marine air masses onto the west coast can readily explain the small west-to-east gradient depicted in this region.

In the Rocky Mountain region and the Southwest, dry, continental air masses are the dominant synoptic feature, whereas in the Smoky Mountain region in the Southeast the influence of moist maritime tropical air masses becomes important, especially in the summer when the Bermuda high pressure circulation frequently drives warm, moist air northeastward from the Gulf of Mexico. Higher relative humidity promotes the growth of small hygroscopic particles into the size range of 0.1 to 1.0 μm where they can act as effective scatterers of visible light and increase atmospheric turbidity (Covert et al., 1972). A number of authors, including Peterson et al. (1981), Berri and Peterson (1978), and Flowers et al. (1969), have demonstrated the dependence of atmospheric turbidity on air mass type trajectory. Natural emissions and photochemistry may also contribute to higher turbidity over the Smoky Mountains. Although the actual importance of this effect has not been firmly established, the reports of Reisinger and Crawford (1980) and Adams et al. (1980) both identify the United States coastal areas along the Gulf of Mexico as significant source regions of biogenic sulfur gas emissions during the summer months. These emissions are active candidates for photochemical reactions leading to the formation of sulfate and sulfuric acid aerosols with a subsequent impact on turbidity.

Anthropogenic sources of primary particles and precursors to secondary particles are also greater in the Southeast than they are in the Southwest and Rocky Mountains, and these anthropogenic sources also may contribute to higher average turbidities in the Southeast. It should also be pointed out that synoptic weather patterns combine to cause a region of maximum frequency of stagnant high pressure systems over the southern Appalachian region (Korshover, 1967), and that these weather patterns also can be important factors in the occurrence of high regional turbidity conditions through a reduction in atmospheric mixing and dispersion.

By comparing Figure 2 to the analysis of annual average background turbidity for 1961-1966 in Figure 3 (Flowers et al., 1969), changes in background turbidity since the early 1960's can be estimated. Figure 4 shows the results of a comparison based on graphical subtraction . Because of changes in the monitoring network and the empirical method of determining background sites, this comparative analysis should only be taken as generally indicative of the possible trend. Nevertheless, the observed turbidity increases east of the Mississippi and particularly in the Southeast shown in Figure 4 are believed to constitute real increases in annual average background turbidity. The regional-scale growth and increasing urbanization and industrialization of the South as increasing numbers of industries and people move to the area are considered to be at least partly responsible for this trend.

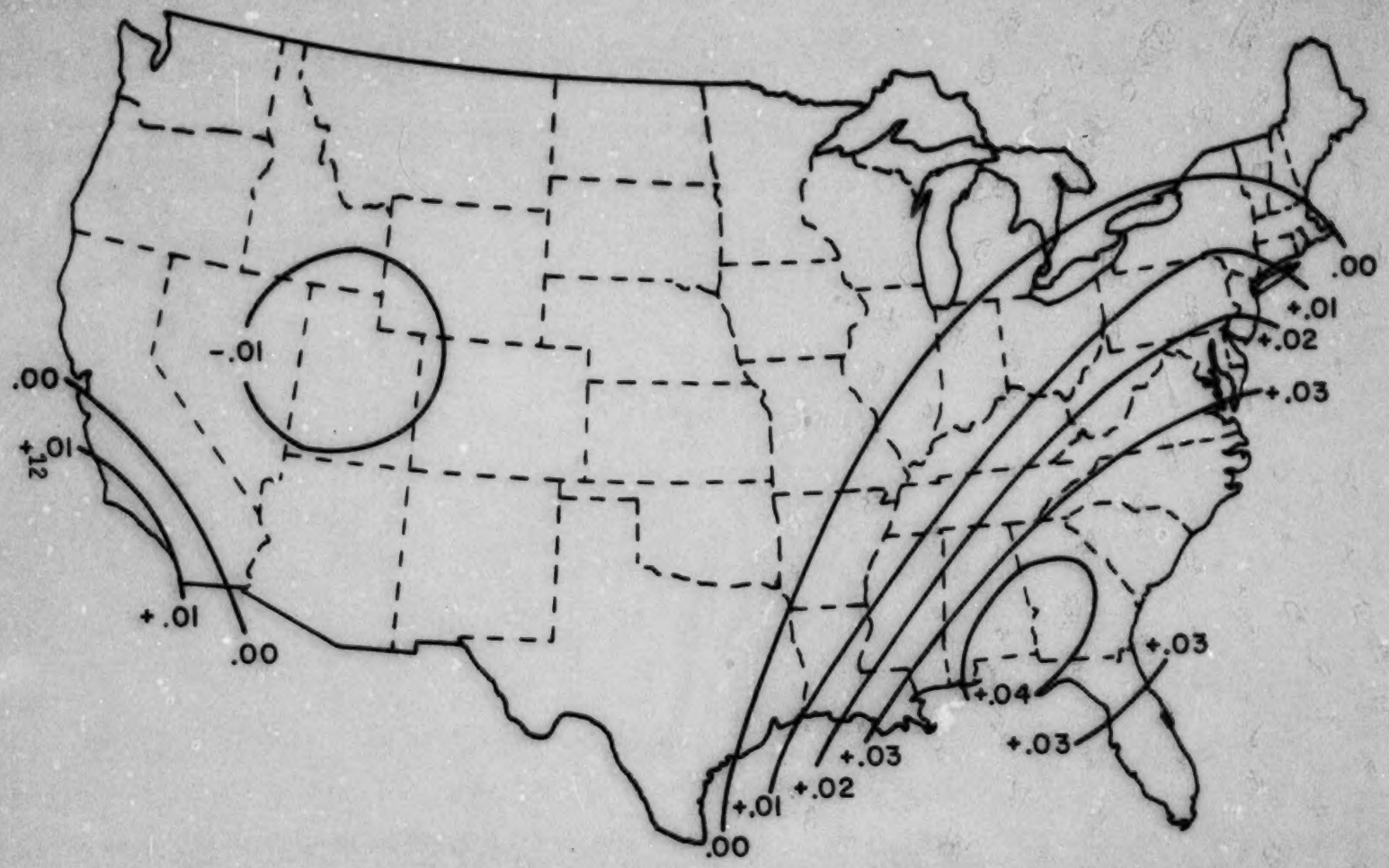


Figure 4. Change in annual average background turbidity between 1961-1966 and 1967-1976.

In the southwest, unfortunately, data sets for the large, rapidly growing cities in this sun-belt region of generally low turbidity are not available. The slight decrease in turbidity over the Rockies shown in Figure 4 is not believed to be significant; this change is more likely due to an increase in the number of monitoring sites and a realignment of the pattern in the Rocky Mountain region rather than to a real decrease in turbidity. The general lack of a detectable increase in the whole area north and west of the line from Texas to the Great Lakes was unexpected in light of the large population and energy production growth in this area during this decade.

Flowers et al. (1969) showed clearly that most stations had a seasonal turbidity cycle with a summer maximum. The present analysis shows a similar pattern. Also in those areas where the turbidity showed a gradual increase over 1961-66 values and during the 1967-76 decade the increases in annual average turbidity have been dominated by greater increases in the summer season than in other seasons. Many sites in the middle Atlantic and southeastern states show strong upward trends for the summer with little change for the winter. This aspect was examined in detail.

Seasonal average background turbidity patterns for 1967 to 1976 are shown in Figures 5 thru 8. In general the seasonal cycle in background turbidity shows the lowest values occurring in the winter and highest values in the summer. In the winter, as shown by Figure 5, the Rockies and the western states experience low values of turbidity while over the east coast and southeast states turbidity tends to be up to 3 times the western values. Figure 6 shows the average spring turbidity pattern for the 1967-76 decade. Compared to the winter conditions springtime turbidity increased by approximately a factor of 2 in all areas of the country. The gradient between the west and the southeast is clearly evident.

Summertime background turbidity is shown by Figure 7. In the western states and the northern great plains there is little apparent change from spring to summer. However, in the southeast turbidity is approximately 2 times the spring values, from a spring maximum of 0.16 in the Appalachians to a turbidity coefficient of 0.30 in the summer. The average turbidity conditions for the fall, as shown by Figure 8, are generally similar to the spring pattern but with somewhat smaller values in most areas.

More detailed analyses would show that this seasonal cycle is observed generally at all network sites, although the amplitude of the cycle varies from region to region. Slower moving stagnant air masses, greater solar radiation leading to increased production of natural and anthropogenic photochemical aerosols, and higher relative humidities associated with maritime tropical air masses are some important factors which can contribute to the summer maximum in turbidity. As mentioned previously, Flowers et al. (1969) also reported seasonal cycles and higher turbidity values in the summer.

There are regional differences in the annual cycle of background turbidity. Figure 9 shows the graphically determined difference between summer and winter average background turbidity over the U.S. based on the

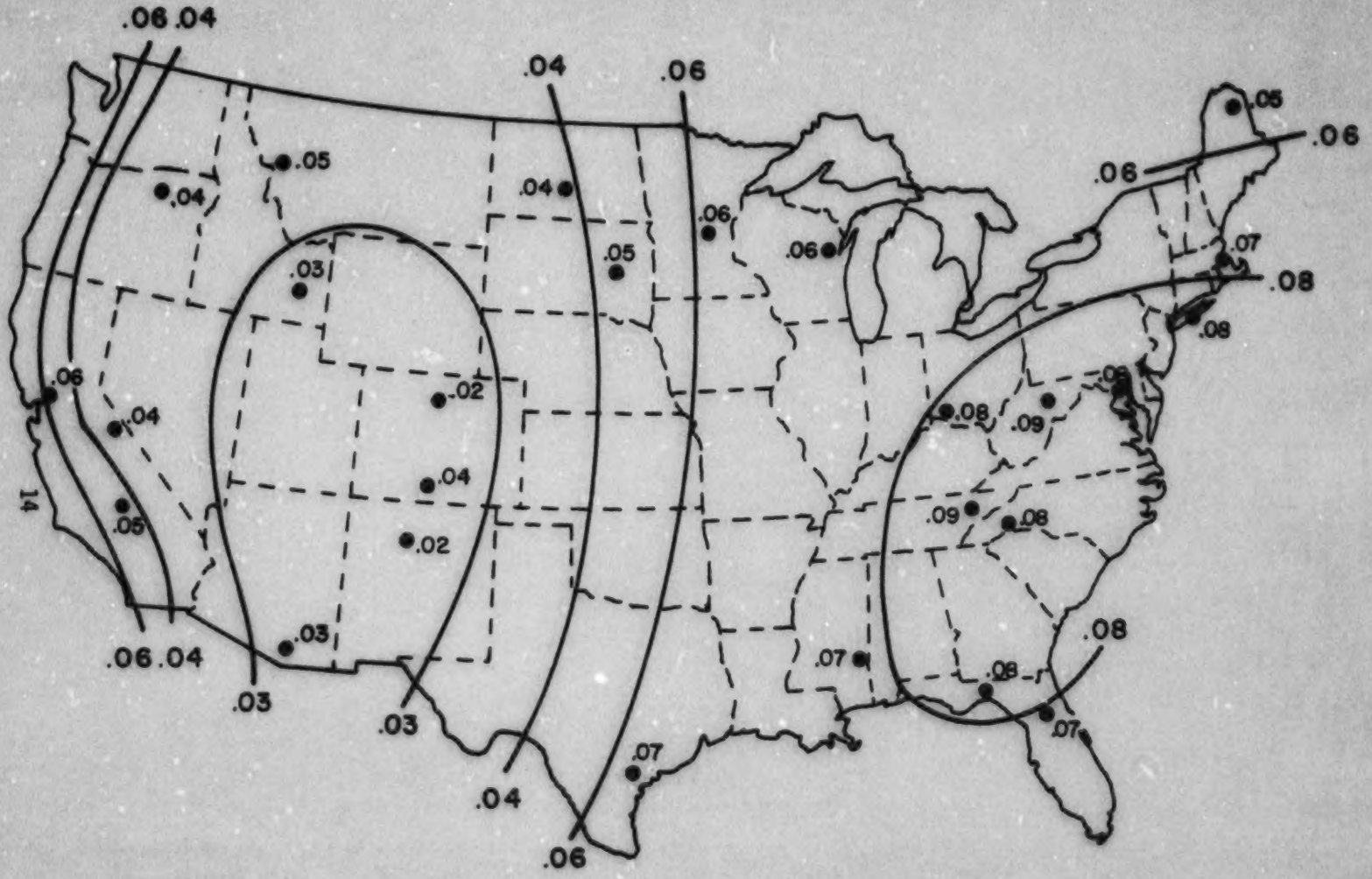


Figure 5. Winter average background turbidity, 1967-1976.

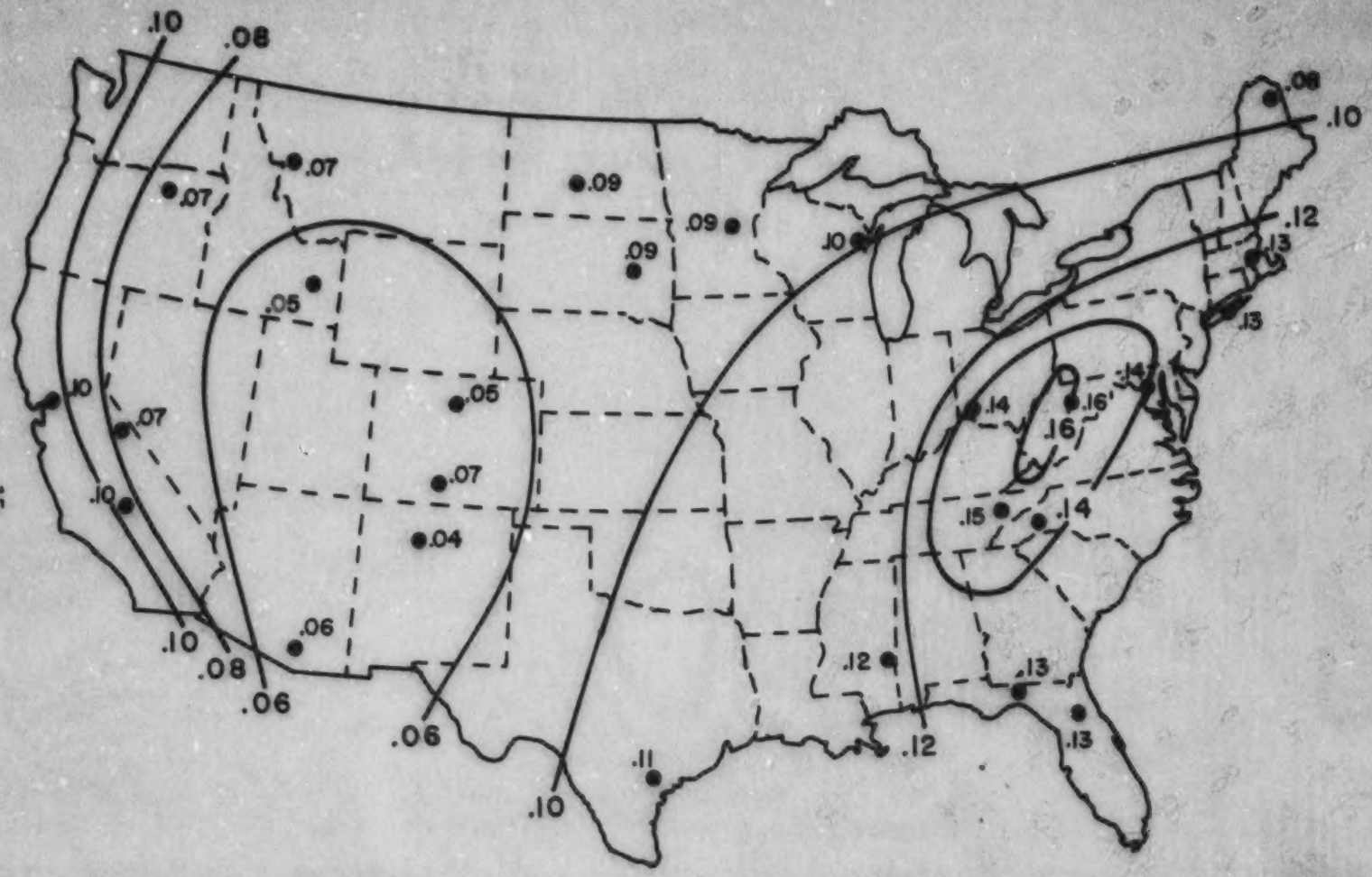


Figure 6. Spring average background turbidity, 1967-1976.

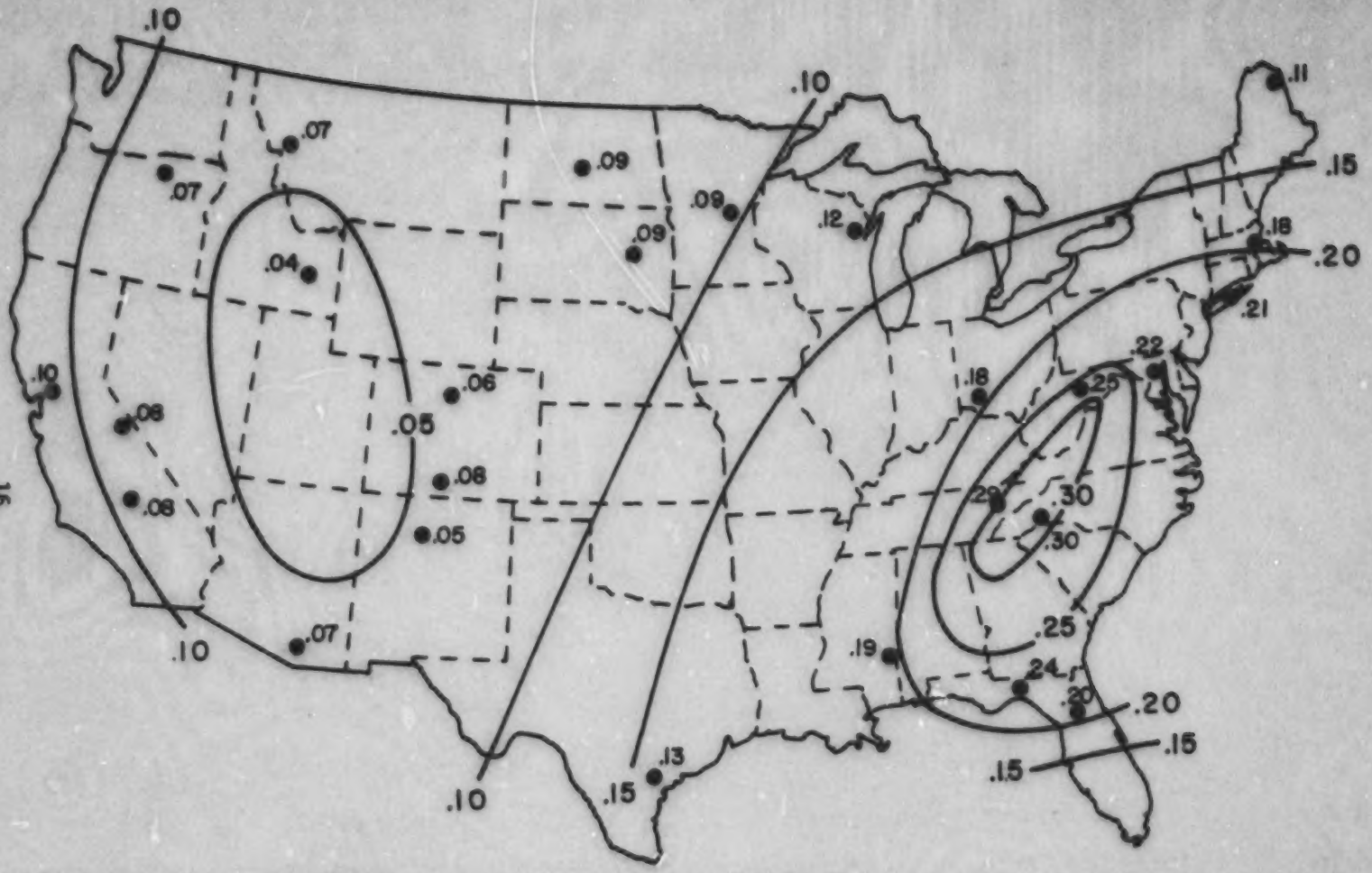


Figure 7. Summer average background turbidity, 1967-1976.

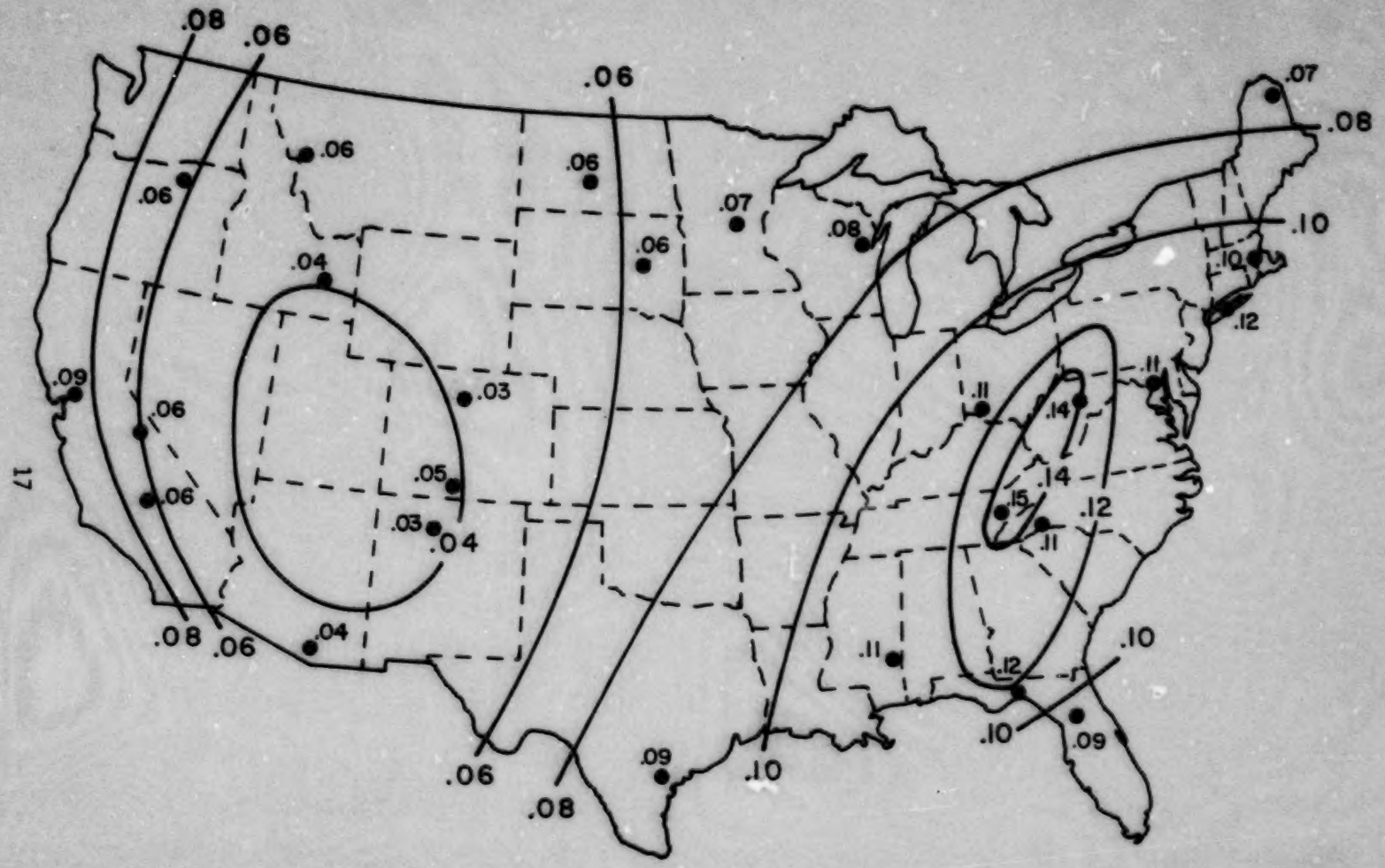


Figure 8. Fall average background turbidity, 1967-1976.

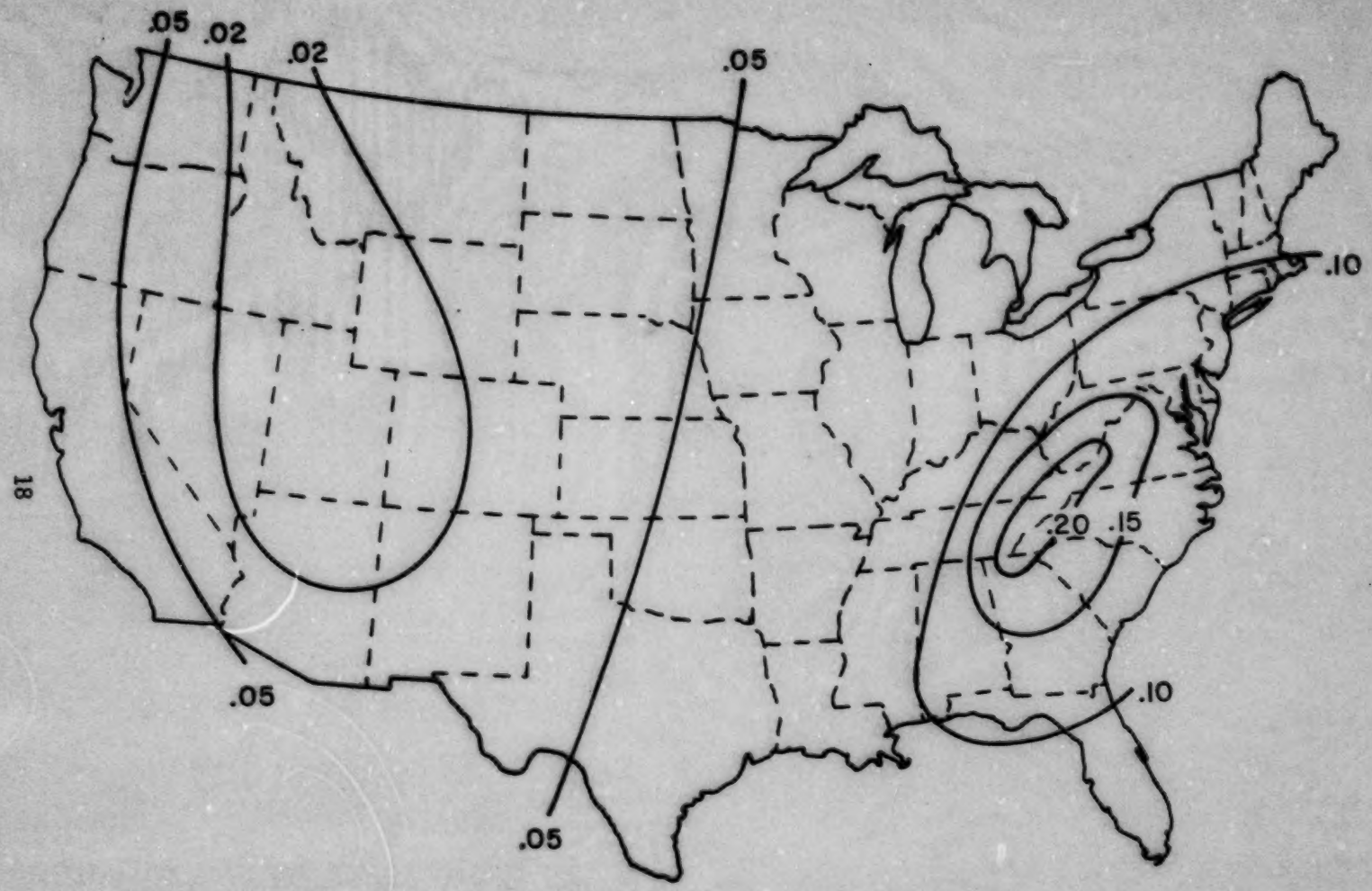


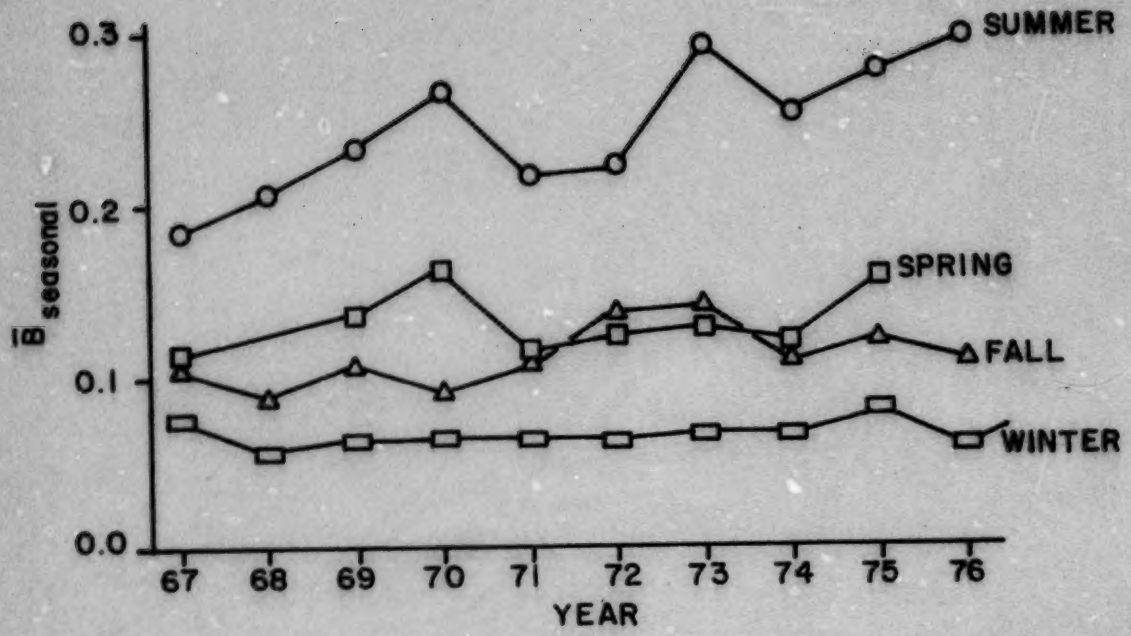
Figure 9. Amplitude of the annual cycle in seasonal average turbidity, 1967-1976.

data for the period 1967 thru 1976. The amplitude of the annual cycle in seasonal average turbidity is greatest over the Smoky and Southern Appalachian Mountains (ΔB = 0.15 to 0.20) and smallest over the Rocky Mountains and the Southwest (ΔB = 0.02 to 0.04). Over the Smoky Mountain region, clear skies in the summer are frequently associated with warm, moist tropical air masses. In the winter clear skies suitable for turbidity observations are frequently associated with drier, faster moving continental air masses. These synoptic factors and the annual cycle in the photochemical production of natural aerosols in the deciduous forests of the Smoky Mountains and wet low lands of the Gulf Coast, are possible explanations for the large annual cycles in turbidity of the southeastern states shown in Figure 9. It should be re-emphasized, however, that the relative importance to turbidity of natural emissions either of hydrocarbons or sulfur compounds is only speculative and has not been firmly established. In contrast to the southeast states, over the Rocky Mountains the differences between predominant air masses in winter compared to summer are less sharp. Clear skies in all seasons are frequently associated with relatively dry continental air masses and daytime mixing usually penetrates to high levels providing a dilution of surface generated constituents. These factors apparently contribute to the small amplitude of the annual cycle in seasonal average background turbidity over the Rocky Mountains.

TURBIDITY TIME TRENDS DURING THE 1967-76 PERIOD

The previous described research results have clearly shown that the seasonal turbidity characteristics differ in different regions of the United States. Further details of these regional differences were determined through an examination of seasonal time trends over the 1967-76 decade at specific sites across the country. The results are shown in Figures 10 though 18. The sites examined are: Oak Ridge, TN, Greensboro, NC, and Meridian, MS, from the southeastern states; Little Rock, AK, in the southern Mississippi Valley; New York City in the northeast area; Green Bay, WI, St. Cloud, MN, and Huron, SD, in the upper midwest, and Missoula, MT, in the western mountain region. The selection of these sites was limited to those stations with reasonably complete observational records. Data adequacy criteria for these averages were mentioned previously. Although these average values are not continuous variables, linear regression calculations for the trend plots have provided a general quantitative measure of the rate of change of the seasonal and annual average turbidity at these sites for the period 1967- to 1976. The results of the regression calculations are given in Table 3 and are discussed below.

The plots for Oak Ridge, TN, Greensboro, NC, and Meridian, MS (Figures 10, 11, and 12) are typical for sites in the Smoky Mountain and southeastern region of the United States. Slight increases in annual average turbidity, over the period, as shown at the bottom of the figures, are due mainly to strong increases in the summer average values, as shown by the seasonal trends in the upper portion of each figure and the higher correlation coefficients and regression slopes in Table 3. Interestingly, trends in the winter, spring, and fall average values at these three sites are not pronounced, and low values for the slope and correlation coefficients for these seasons were obtained. There is some evidence for changes



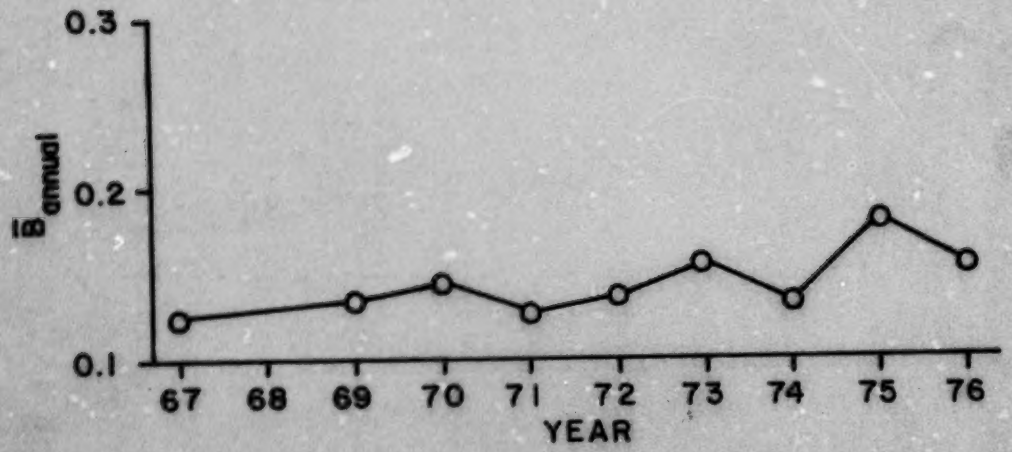


Figure 10. Seasonal and annual trends in mean turbidity at Greensboro, NC.

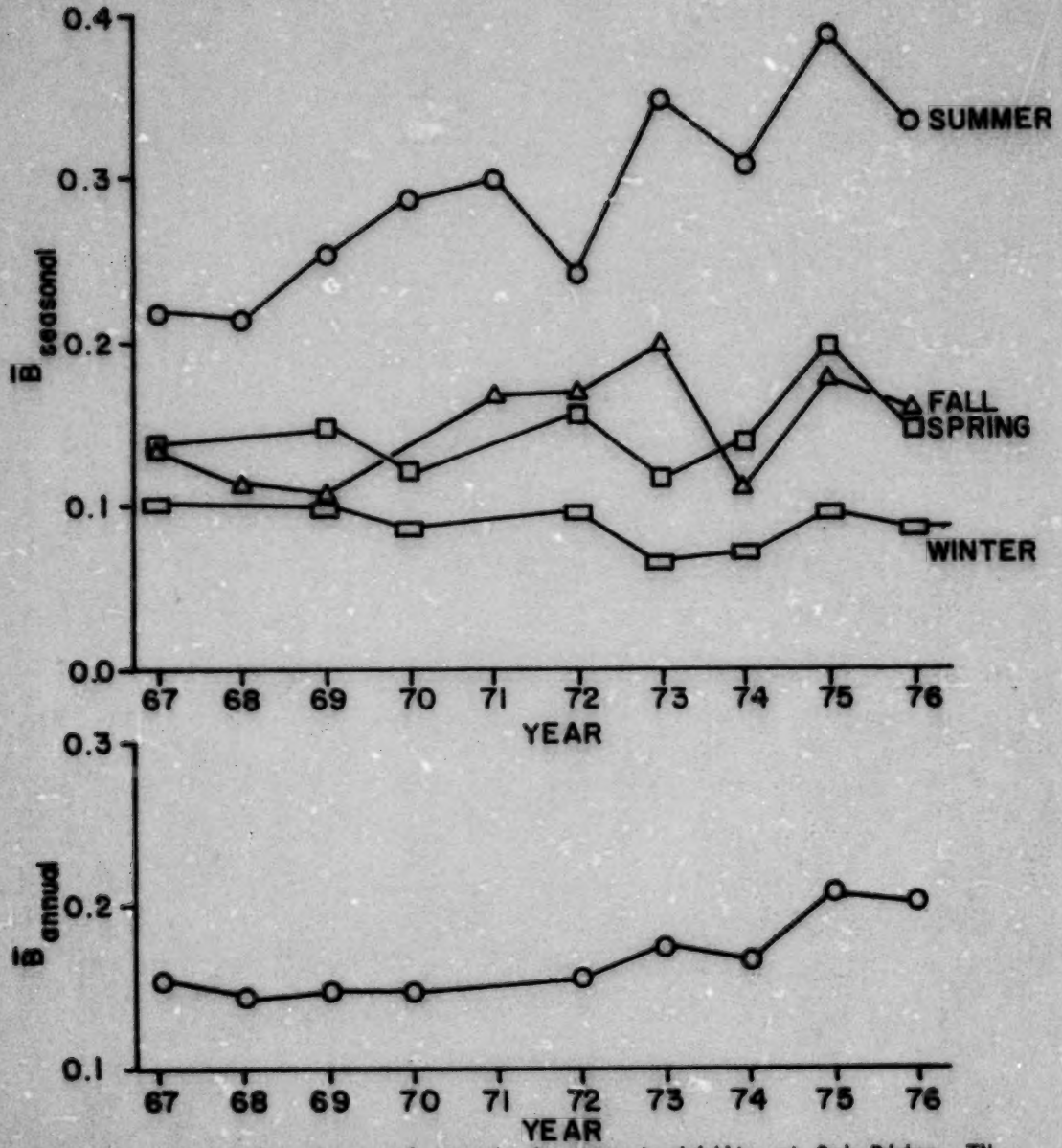
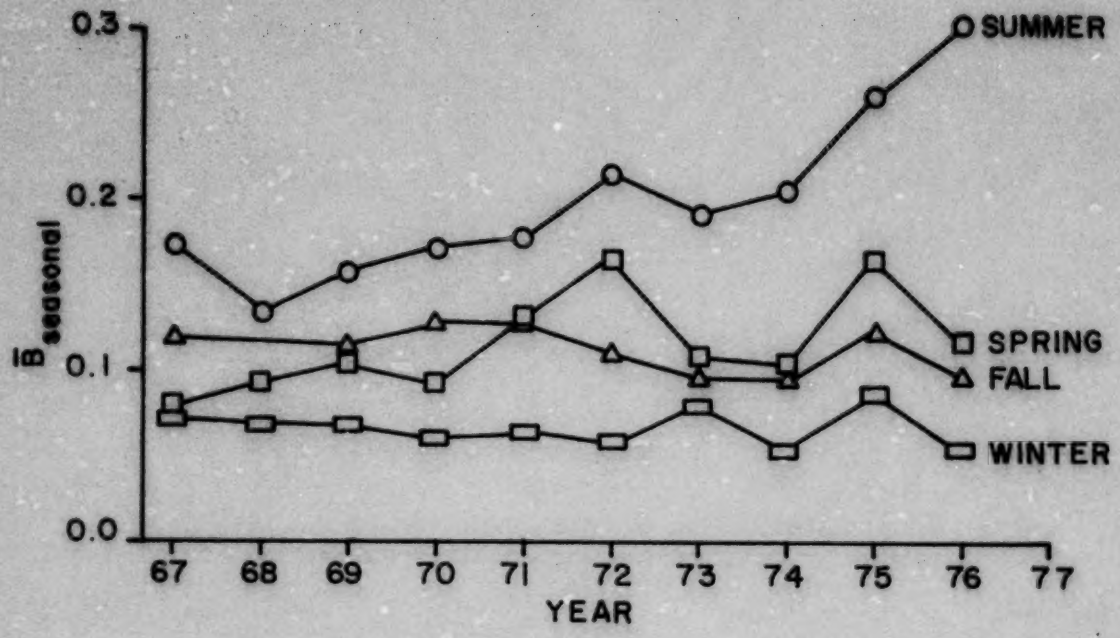


Figure 11. Seasonal and annual trends in mean turbidity at Oak Ridge, TN.



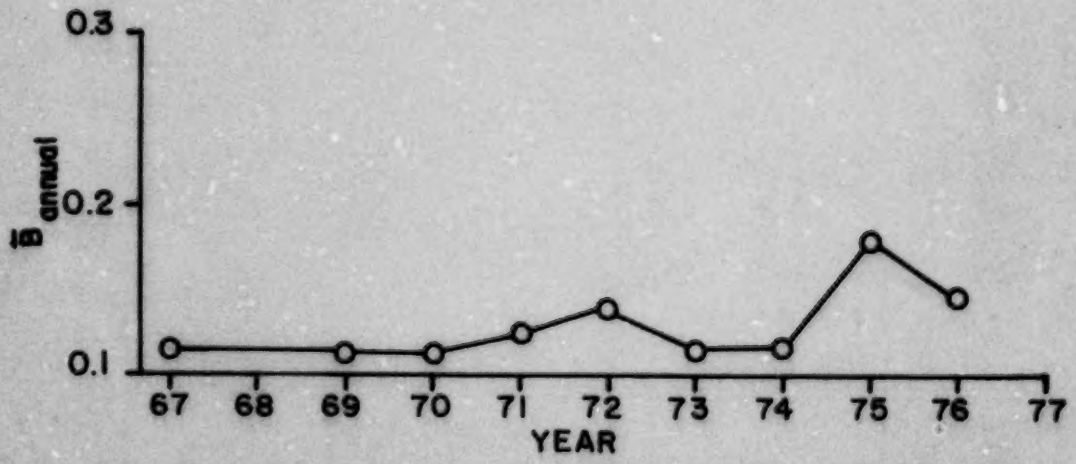


Figure 12. Seasonal and annual trends in mean turbidity at Meridian, MS.

Table 3. Linear regression equations for seasonal and annual average turbidity trends at selected sites for 1967 to 1976.

Site	Equation	Correlation Coefficient, r
Oak Ridge, TN		
Winter	B* = -0.0018Y** - 0.218	-0.42
Spring	B = 0.0027Y - 0.052	0.34
Summer	B = 0.016Y + 0.882	0.86
Fall	B = 0.0055Y - 0.244	0.50
Annual	B = 0.0061Y - 0.268	0.83
Greensboro, NC		
Winter	B = 0.0010Y - 0.009	0.36
Spring	B = 0.0015Y + 0.022	0.23
Summer	B = 0.010Y - 0.499	0.74
Fall	B = 0.0028Y - 0.094	0.52
Annual	B = 0.0036Y - 0.113	0.62
Meridian, MS		
Winter	B = -0.0015Y + 0.077	-0.04
Spring	B = 0.0042Y + 0.089	0.05
Summer	B = 0.0151Y - 0.871	0.86
Fall	B = 0.0024Y - 0.0627	0.29
Annual	B = 0.0049Y - 0.225	0.65
Little Rock, AR		
Winter	B = 0.0070Y + 0.060	0.17
Spring	B = 0.0031Y - 0.037	0.64
Summer	B = 0.0057Y - 0.130	0.70
Fall	B = 0.0021Y - 0.0034	0.33
Annual	B = 0.0025Y - 0.0065	0.61
New York, NY		
Winter	B = -0.0054Y + 0.492	-0.70
Spring	B = -0.0036Y + 0.415	-0.49
Summer	B = -0.0118Y + 1.073	-0.81
Fall	B = -0.0097Y + 0.831	-0.76
Annual	B = -0.0062Y + 0.598	-0.78

TABLE 3--(Continued)

Site	Equation	Correlation Coefficient, r
Green Bay, WI		
Winter	B = 0.0012Y + 0.027	0.27
Spring	B = -0.0016Y + 0.2271	-0.39
Summer	B = 0.001Y + 0.043	0.16
Fall	B = -0.0015Y + 0.191	-0.31
Annual	B = -0.0002Y + 0.1082	-0.07
Huron, SD		
Winter	B = 0.00546Y - 0.3343	0.82
Spring	B = -0.00117Y + 0.1726	-0.20
Summer	B = 0.00379Y - 0.1769	0.61
Fall	B = 0.00149Y - 0.0424	0.31
Annual	B = 0.00229Y - 0.0868	0.56
St. Cloud, MN		
Winter	B = -0.00017Y + 0.0743	-0.04
Spring	B = -0.00266Y + 0.2700	-0.75
Summer	B = -0.00277Y + 0.2919	-0.54
Fall	B = -0.00142Y + 0.1708	-0.45
Annual	B = -0.00230Y + 0.2439	-0.82
Missoula, MT		
Winter	B = -0.00114Y + 0.1324	-0.19
Spring	B = -0.00197Y + 0.2179	-0.50
Summer	B = -0.00329Y + 0.3054	-0.73
Fall	B = -0.00509Y + 0.4306	-0.75
Annual	B = -0.00367Y + 0.3300	-0.70

* average turbidity

** year minus 1900

in the frequency distribution for winter values in the Southeast although these data do not show it. For example, Peterson and Flowers (1977), showed a reduction in the frequency of winter turbidities less than 0.04 at Meridian, MS, and Raleigh, NC from 1960 to 1975. In a more detailed analysis of the Raleigh, NC data Peterson et al. (1981) were able to identify both seasonal and diurnal cycles in the turbidity patterns. Correlations with air mass parameters were also identified. In the present seasonal data the trends are most significant for the summer season values with increasing summer turbidity occurring over the 10-year period. Possible seasonal influences are the summertime maxima in absolute humidity, temperature, and solar radiation which provide optimum conditions for increased turbidity. The annual trend may be a result of increased industrialization and/or urbanization. Husar et al. (1979), have described the strong increases in coal consumption in the Smoky Mountain region since the early 1960's.

In comparison to the 3 southeastern stations, the plot for Little Rock, AK (Figure 13) in the southern Mississippi Valley, exhibits only a very slight increase in annual average turbidity over the period. This annual trend is due mainly to a slight increase in summer average values. The value of the regression slope in Table 3 for Little Rock in the summer indicates a rate of turbidity increase of only about one third the upward trend in Oak Ridge, Greensboro, or Meridian. This turbidity trend at Little Rock may be due to increased fossil fuel consumption in the area south and west of the station, in the direction of Texas. Thus the strong summer turbidity trend seems to be relatively limited in geographical extent to an area generally east of the Mississippi. This might also have been inferred from Figure 4.

New York City urban observations shown in Figure 14 and the regression results in Table 3 indicate decreasing annual, summer, fall, and winter average values over the 1967-76 decade. The regression line for spring also has a slightly negative slope, but the correlation coefficient, -0.49, is poorer than those for the other seasons. Interestingly, this decreasing trend for the urban observations at New York is accompanied by slight increases in background turbidity for the region (see Figure 4). This may indicate that pollution control efforts have improved the average optical quality of the urban New York atmosphere even though the regional trend was the opposite. Peterson and Flowers (1977) have described a similar trend for another urban station, Youngstown, OH.

Background turbidity trends in the upper midwest are illustrated by Figures 15, 16 and 17 which show the annual and seasonal trends for Green Bay, WI, Huron, SD, and St. Cloud, MN. Average annual turbidity is greater at Green Bay than at Huron or St. Cloud, about 0.1 compared to about 0.07 and 0.08 for the latter 2 stations,but there is no consistent trend at any of the 3 stations over the 10-year period. The small downward trend at St. Cloud from an average of .084 for the first 3 years of the period to 0.074 in the last 3 years is not statistically significant. Each station shows, in general, the greatest average turbidity during the summer but no year-to-year trend is discernible in either the summer data or in any of the other seasons. The differences between winter and summer turbidity are also relatively small compared to the stations in the southeast, as shown in Figure 9. A small

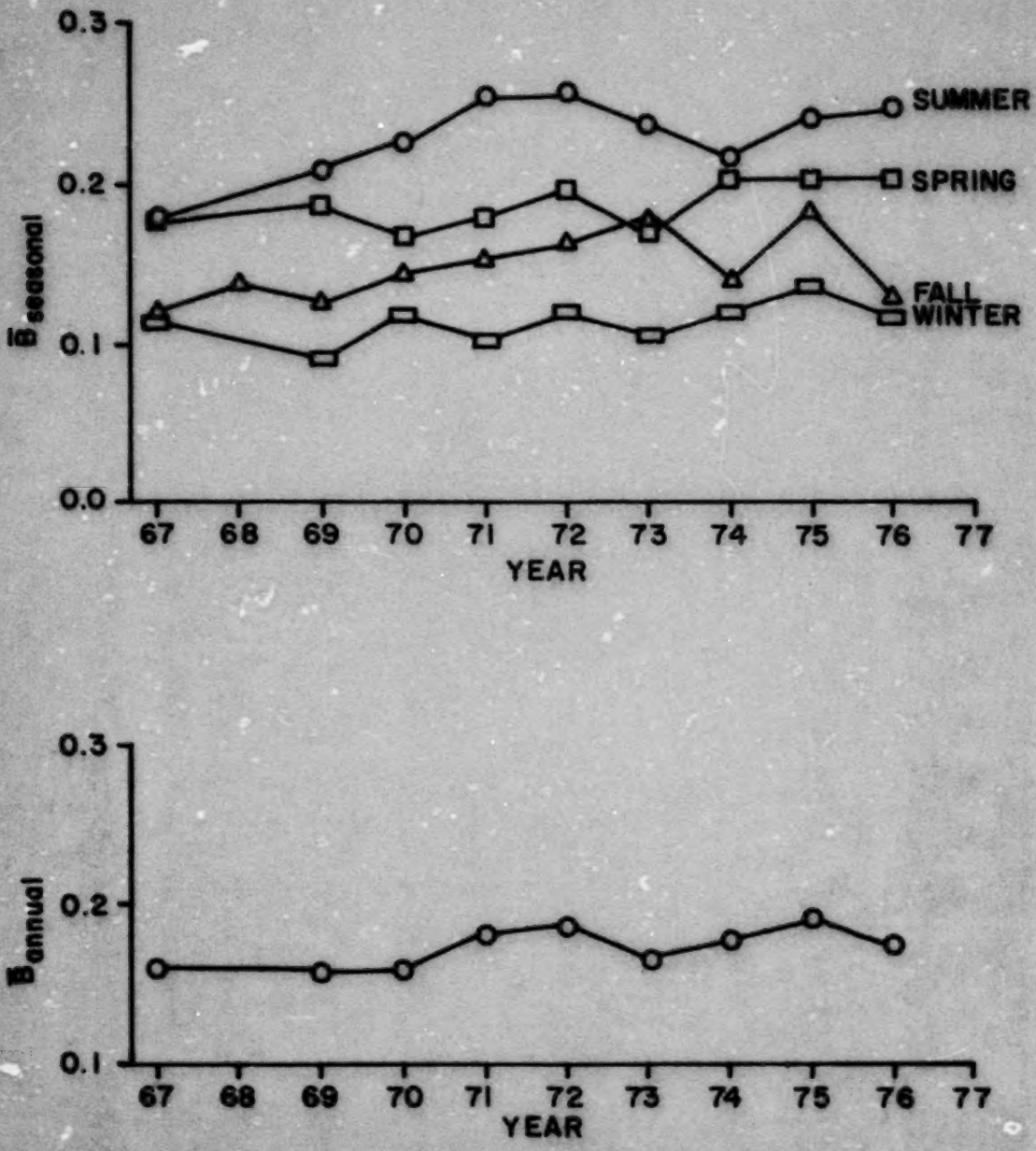
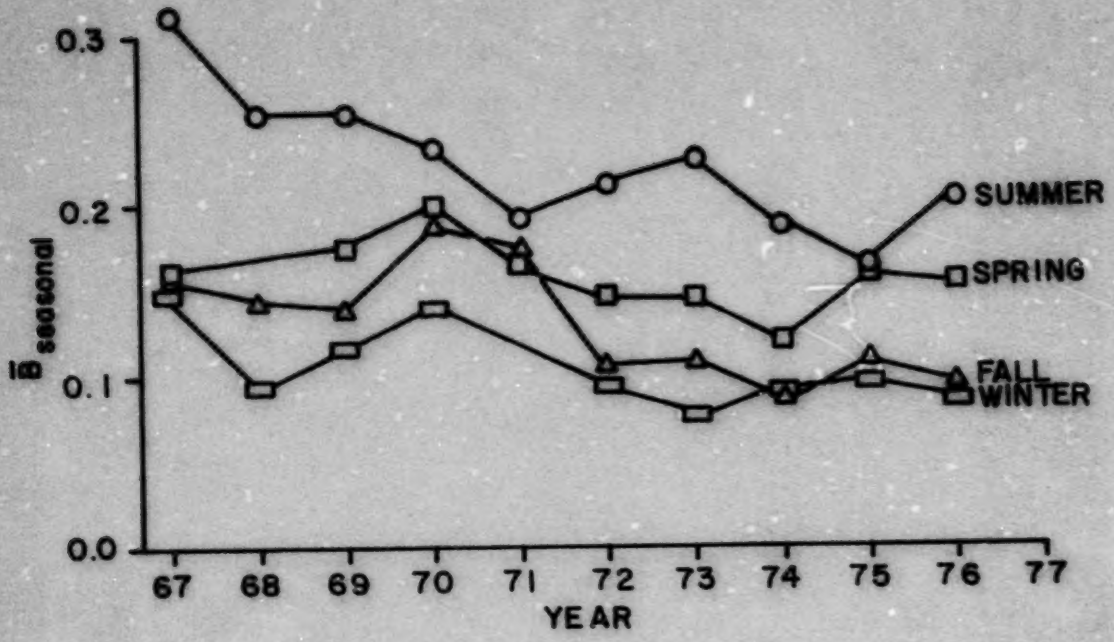


Figure 13. Seasonal and annual trends in mean turbidity at Little Rock, AR.



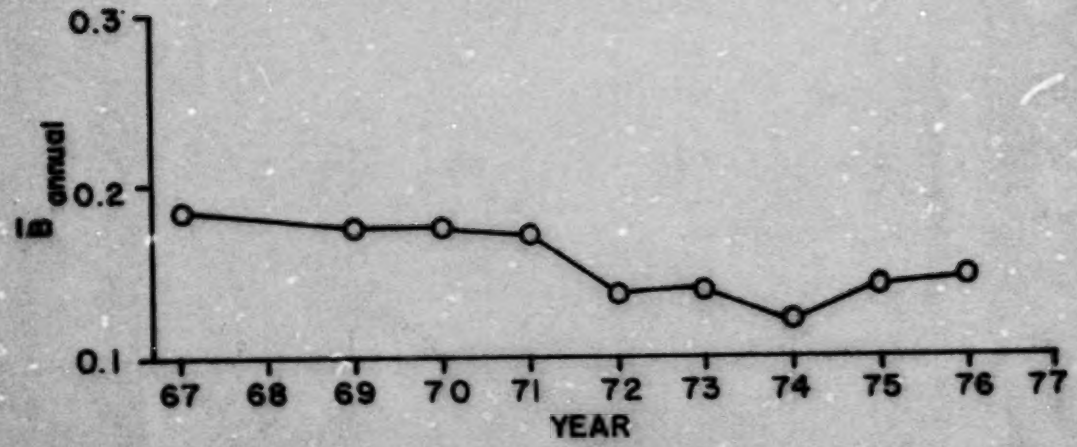
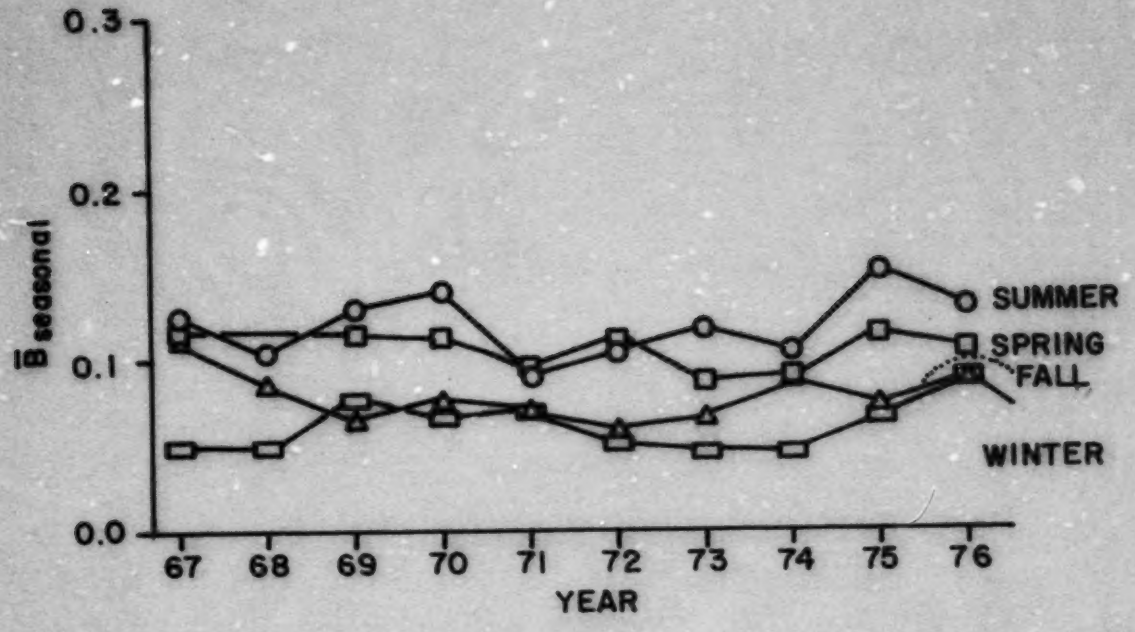


Figure 14. Seasonal and annual trends in mean turbidity at New York, NY.



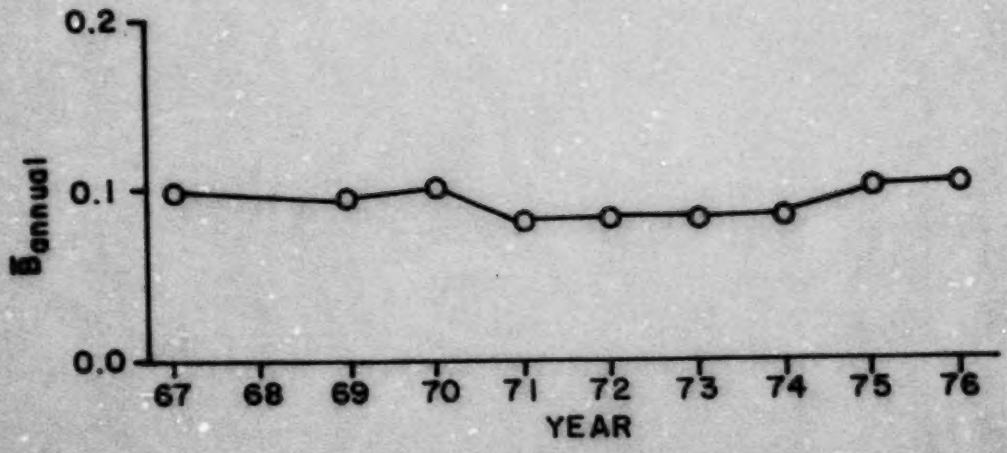
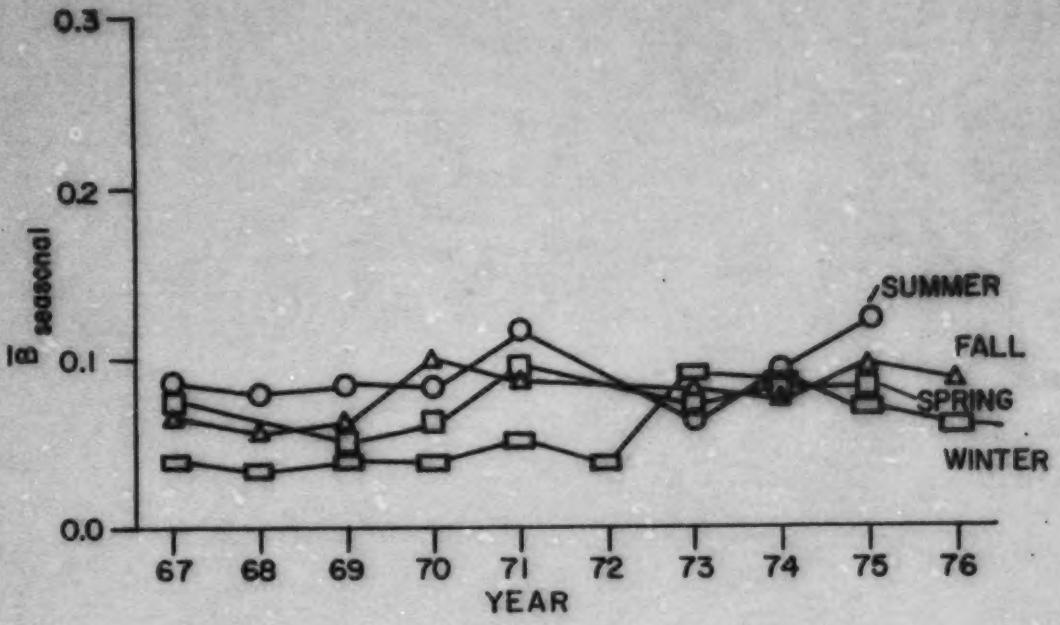


Figure 15. Seasonal and annual trends in mean turbidity at Green Bay, WI.



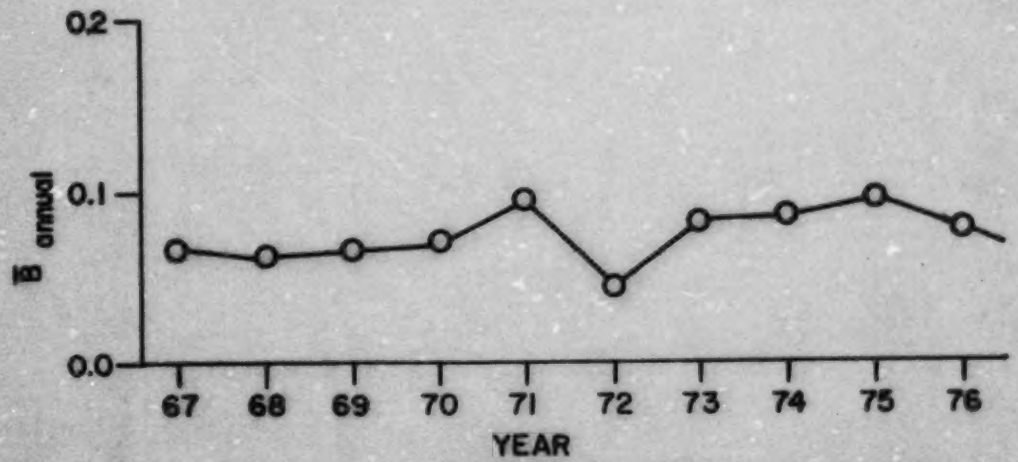


Figure 16. Seasonal and annual trends in mean turbidity at Huron, ND.

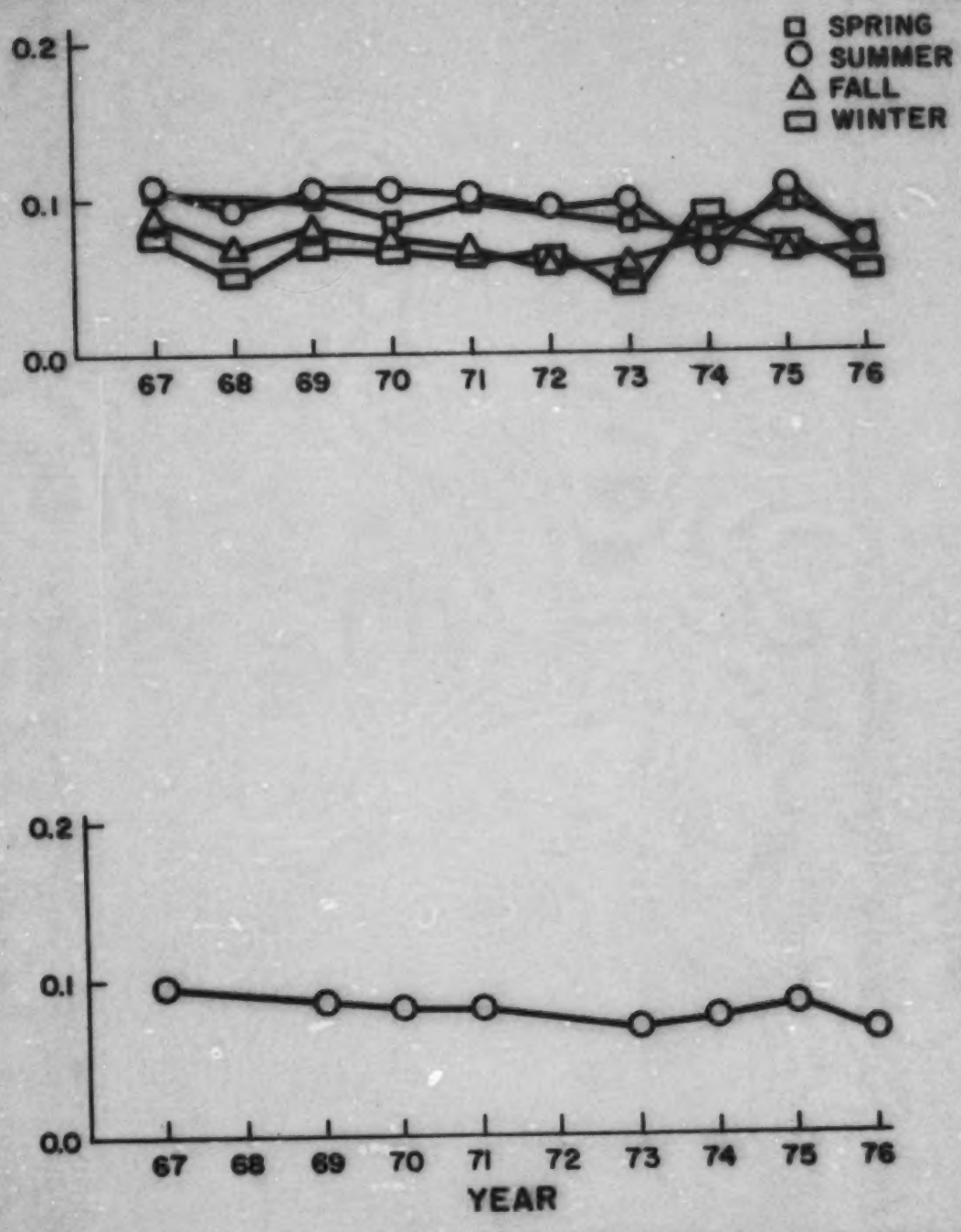


Figure 17. Seasonal and annual trends in mean turbidity at St. Cloud, MN.

winter-summer difference is characteristic of the upper midwest as well as of the west and southwest.

Figure 18 shows the annual and seasonal turbidity trends for Missoula, MT in the Rocky Mountain region. The annual trend at Missoula indicates a slight trend toward decreasing turbidity which, as indicated by the seasonal plots is due apparently to changing winter conditions. The trends of the seasonal turbidity values do not show differences between seasons. In the annual record the 1969 value of 0.10 stands out and was looked at in detail. The value is the result of a few high turbidity days in the winter and in June, 1969 while most of the other data are generally around 0.08. Thus a trend downward from the 1969 turbidity value is not considered reliable.

DISCUSSION OF TURBIDITY TRENDS

The turbidity data from the EPA turbidity network in the United States for the 1967-1976 decade lead to several conclusions about the climatology of turbidity during this period. Maximum annual average background turbidity occurs over the Southeast and the Smoky Mountain region and minimum annual average background turbidity occurs over the Rocky Mountains and the interior Southwest. This geographical variation was shown to be characteristic of all four seasons. An annual cycle in turbidity is recognizable in all the regional areas. Maximum seasonal average turbidity occurs in the summer and minimum seasonal average turbidity occurs in the winter in all regions. The amplitude of this annual cycle is greatest over the Southeast and smallest over the Rocky Mountain region.

Results also indicate increases in turbidity, especially in the summer season, over the Southeast and the Smoky Mountain region since the early 1960's. Increasing urbanization and industrialization in the South are believed to be the causes for this trend. The lack of trend toward increasing turbidity in areas outside the southeastern states is apparently contrary to visibility trends found in many areas. Trijonis (1979), for example, postulates a decreasing visibility trend in the southwest where the turbidity data, admittedly sparse, do not show such a trend. Reasons for this difference other than the very few turbidity stations are not clearly identifiable but there are several possibilities. For example, the sun photometer measurements because of restrictions due to cloudy sky and a limited number of observations per season may not be numerous enough to detect relatively small changes such as would occur in the relatively clean environment of the southwestern states. Also, sun photometer sensitivity decreases in conditions of very low turbidity (Flowers et al., 1969).

The subjective link between increasing summer turbidity and atmospheric sulfates is supported by the studies of seasonal trends in sulfate concentrations in the period 1963-1975 by Altshuller (1980). In his study Altshuller found an upward trend in June, July, and August sulfate concentrations at nonurban sites in the east and midwest. This is similar to the turbidity trends observed. The sulfate correlation to turbidity is also supported by the visibility studies of Trijonis and Yuan (1978) in the northeastern states where they estimated that about 50% of the visibility restriction over the region could be attributed to sulfate concentrations.

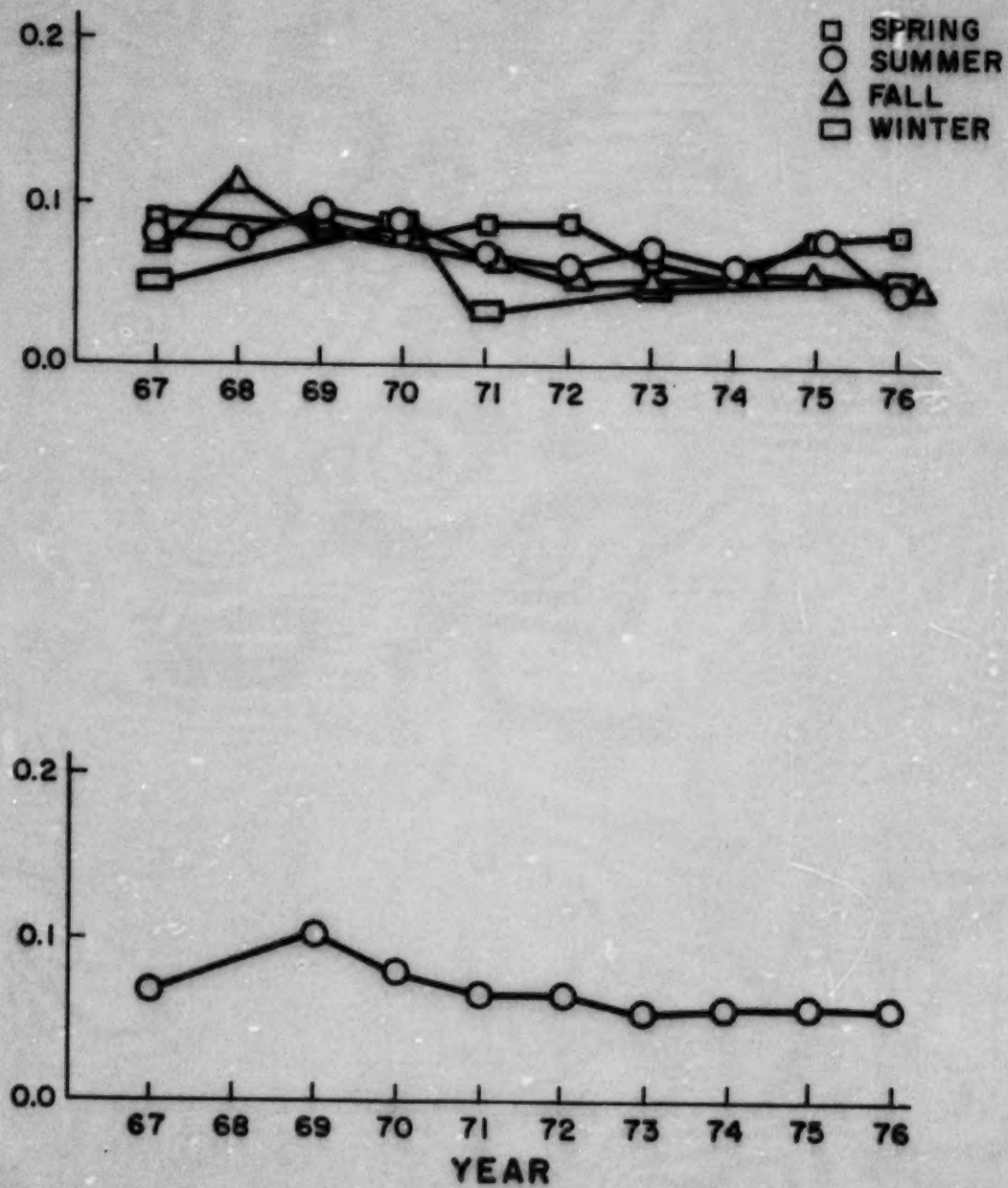


Figure 18. Seasonal and annual trends in mean turbidity at Missoula, MT.

SECTION 4

MODEL RELATING TURBIDITY TO URBANIZATION

In addition to the geographical variation in climatological background turbidity, significant differences also exist between urban and rural areas within the same geographical region. To a less extent differences also exist within a given city or town depending on the location of the monitoring site. For example, Flowers et al. (1969) showed a difference of 0.03 in the long term average turbidity between a downtown Cincinnati, OH site and a site on the edge of town. In the Los Angeles Basin in California detailed turbidity studies describing the turbidity patterns under different wind flows and smog haze conditions have been reported by Peterson and Flowers (1978) and Peterson et al. (1978). Using a helicopter to obtain turbidity profiles in urban and rural Cincinnati areas, McCormick and Baulch (1962) showed that urban turbidity was especially affected by the heavily polluted surface layer.

DERIVATION OF LONG-TERM MODEL

Long-term average atmospheric turbidity at an urban location can be considered as the sum of two effects. The first, background turbidity B_b, is influenced by regional differences in relative humidity, predominant synoptic air masses, long-range transport, etc. The second, the local contribution to turbidity, B_e, is the excess by which the local turbidity exceeds background levels. B_e is influenced by the extent of the urbanization and industrialization of the city where the measurement is made and the influence of any nearby major urban areas. Combining these two factors gives an expression for the long-term average turbidity at any location of the following general form:

$$\overline{B} = \overline{B}_b + \overline{B}_e$$

A model incorporating both of these factors could be applied to predict long-term changes in atmospheric turbidity based on growth projections for urbanized areas. Such a model could be used to predict changes in the optical transparency of the atmosphere related to visibility degradation, changes in solar radiation collector capability, and, possibly, changes in the local climate. The latter climatic application follows from Husar et al. (1979) who have suggested that increases in turbidity can affect diurnal and long-term average temperature patterns.

Several factors influence the turbidity in excess of background, B_e, for a given city or town. Among these are particulate and aerosol precursor emission rates, types of industry, traffic patterns, effectiveness of pollution controls, the influence of other nearby urban centers, etc.

Unfortunately, long term (10-20 years) projections for these parameters are at best difficult. However, one measure of the relative urbanization of a given city which is frequently projected for a variety of purposes is its population. The basis of population is usually that figure reported by the U.S. Census.

To examine the relationship between population and turbidity, $\overline{B}_e$ was calculated for the urban network sites by subtracting the background levels, B_b, obtained by interpolating on Figure 2, from the observed 1967-1976 average turbidity $\overline{B}$. The same data adequacy requirements for annual average values were applied in this process that are described for the other previous tabulations. The network turbidity data and population figures used in this application are given in Appendix B.

Since turbidity at towns and cities located near major urban centers can be strongly influenced by these urban areas, especially when prevailing winds are from the major city to the city or town of interest, a question arises as to which population is appropriate to consider in the correlation between $\overline{B}_e$ and population P. For example, turbidities for Richmond, California, San Bernardino, California; and Grand Prairie, Texas are influenced by San Francisco, California and other cities in the San Francisco Bay Area; Los Angeles, California; and Dallas, Texas, respectively. In order to make some correction for adjacent population centers the population influencing the three sites listed above was taken arbitrarily as the average of the population of the major city and the city of interest. According to available monitoring data, this approach appears to be appropriate for towns 50 to 70 miles downwind from major urban centers in the direction of the prevailing wind. A more sophisticated approach would be to weight the urban population less heavily as the distance to the city of interest increases. However, we believe that there is insufficient turbidity monitoring data to support adequately a more complex type of relationship.

The results of the turbidity/population correlation are presented in Figure 19. This figure shows the correlation between 1970 population, P, and average 1967-1976 turbidity in excess of background levels, $\overline{B}_e$, for the 55 available sites. Linear and polynominal fits were performed; however, three-constant polynominal fits did not give a significantly better correlation than the linear least squares fit. The least squares best fit line is

$$B_e = 3.976 \times 10^{-8} P + 0.009584$$

and the correlation coefficient is 0.76. The line appears curved in Figure 19 because of the semi-log plot. Considering the potential for variation within a given city and the approximate method which has been employed to correct for the influence of nearby urban centers, this correlation is higher than we expected and indicates that more than 50% of the variability is accounted for. This regression equation is based on 55 available turbidity-population pairs. The validity of this statistical relationship was also tested by dividing the data base into 2 independent sets of data and recalculating a relationship for turbidity and population. When the new $\overline{B}/P$ relationship from half the data was used to predict $\overline{B}$ for the other half of the data set, the correlation between predicted and observed $\overline{B}$ was

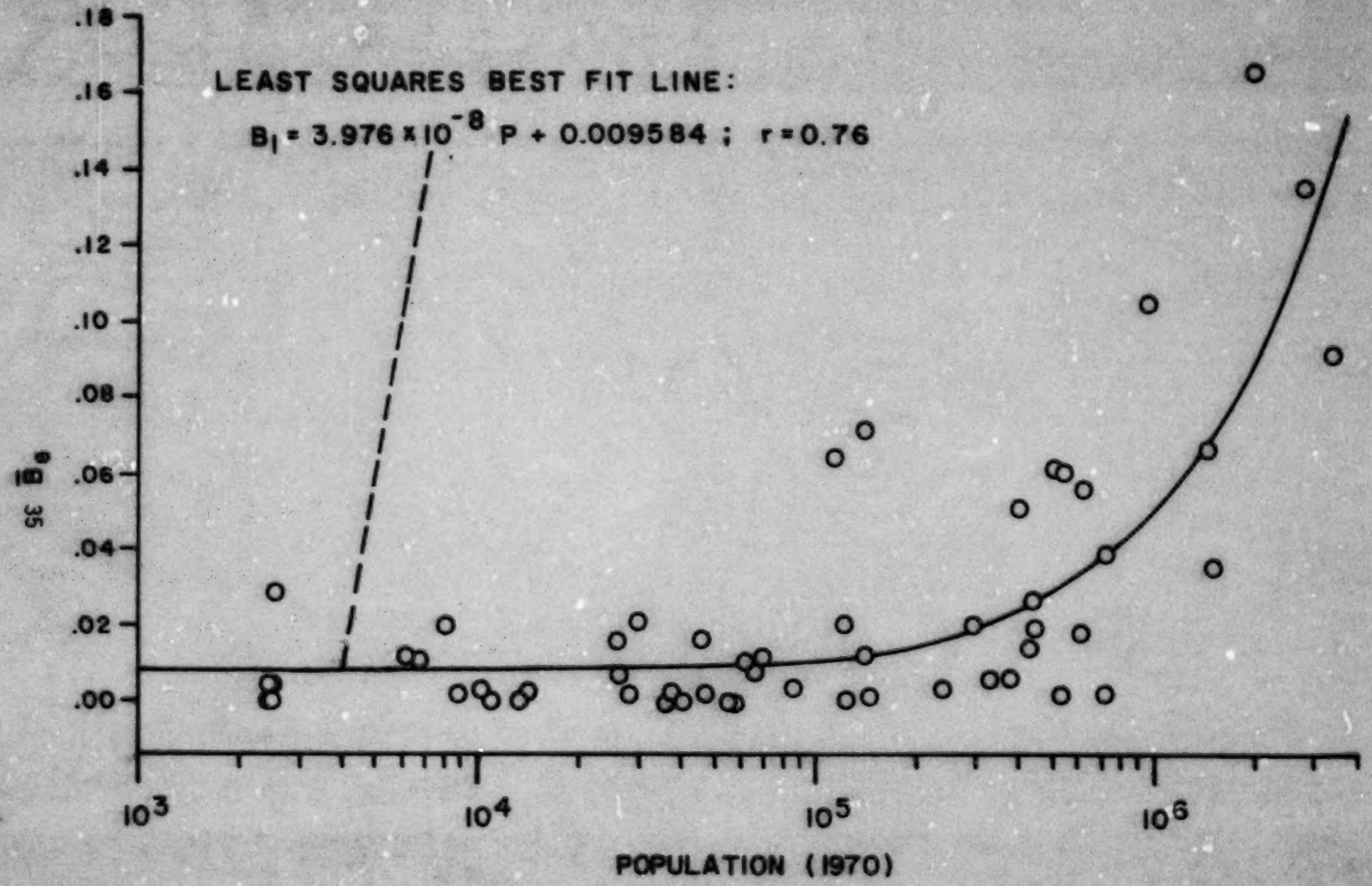


Figure 19. Excess turbidity vs. population at network sites.

0.83. This is quite satisfactory and, in fact, is close to the correlation value of 0.89 calculated between predicted and observed values of $\overline{B}$ determined from the regression equation for the total data set. In figure 20 model predicted turbidity is compared to the observed network values.

As might be expected, at populations below 100,000 there is only a slight excess turbidity above background levels. For cities west of the Mississippi with populations of about 2,000,000 the total urban turbidity ($B_e + B_b$) is roughly double the background levels . Turbidity doubling occurs with populations of about 5,000,000 for cities east of the Mississippi. This difference results from the geographical differences in background levels.

Differentiating the regression expression gives an expression which can be applied to predict changes in mean turbidity based on population growth assuming no change in background turbidity

$$\frac{d\overline{B}}{dP}_e = 3.976 \times 10^{-8}.$$

For example if a city is projected to grow by 1,000,000 people in the next fifteen years, which is not unrealistic for some sun-belt cities, this expression predicts an increase in mean turbidity of 0.040. Since the Southwest currently has mean annual turbidity of 0.06 this increase corresponds to a reduction in the intensity of the direct beam of incoming solar radiation of 5 to 8 percent, depending on the solar elevation angle. To predict the average turbidity for any city whose population and location are known or predicted, evaluate $\overline{B}_b$ by interpolating on Figure 2 and calculate the excess average turbidity $\overline{B}_e$ predicted using the regression equation given above. Adding $\overline{B}_e$ to $\overline{B}_b$ gives the model predicted value of mean annual turbidity $\overline{B}$.

Data from the 1980 U.S. Census can provide population figures which could be used for additional model validation studies. Correlations obtained with data from monitoring sites not considered for the background turbidity plot may be lower than the correlation described above.

MODEL ASSUMPTIONS AND LIMITATIONS

In all predictive models, assumptions and limitations inherent in the model must be addressed. For the turbidity versus population model described above there are two principal assumptions. The first assumption is that the excess average turbidity above background, $\overline{B}_e$, is related to the urbanization and industrialization of a city and thus to the population of the city. The second assumption is that changes in pollution control technology, predominant industries, and climate will not significantly alter the relationship between the population of a city and the excess average turbidity.

The first assumption is logical and is supported by the empirical correlation between population and $\overline{B}_e$ described above. An example where this assumption could limit the accuracy of the model is in the case of a

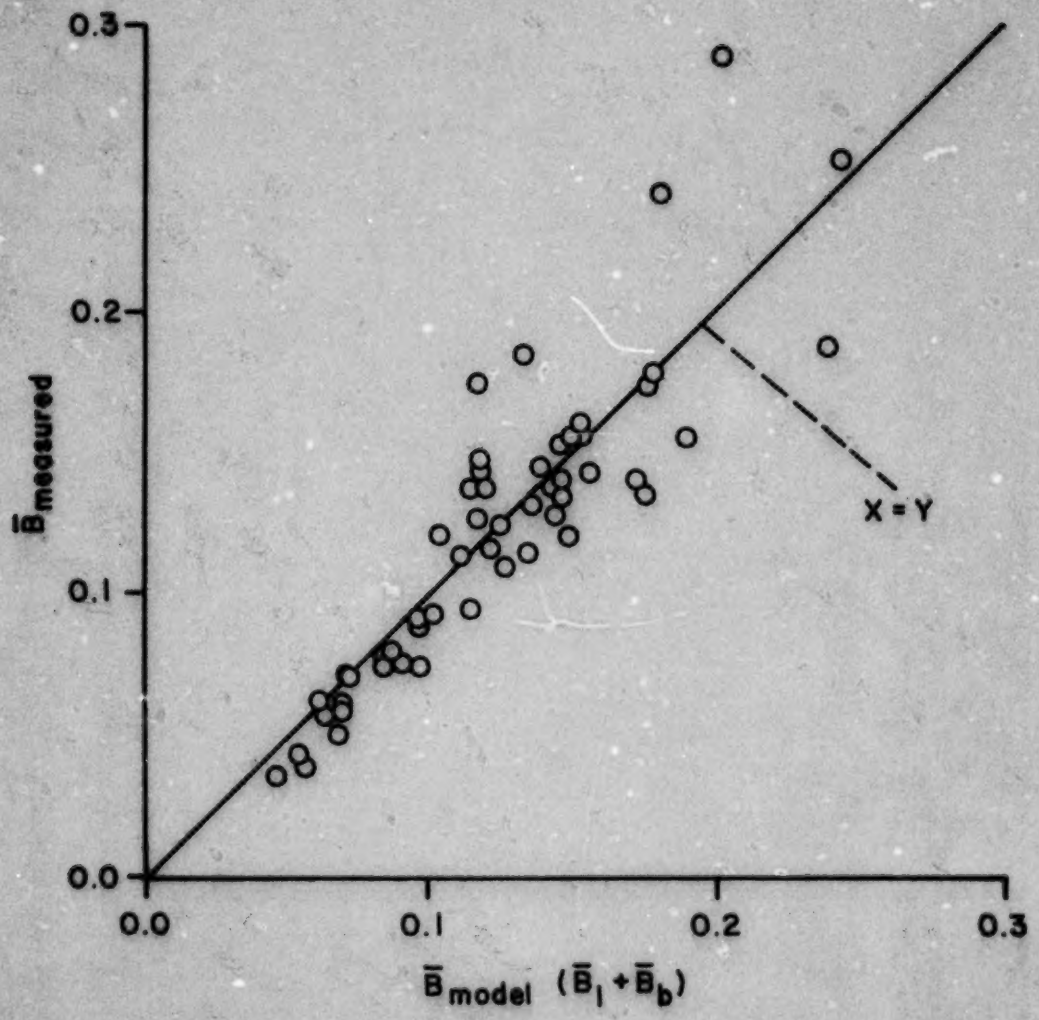


Figure 20. Model predicted mean turbidity compared to measured values.

small town where a single industry produces significant emissions near the population center. Depending on how close the source is to the population center, annual average atmospheric turbidity over the town may be somewhat higher than predicted by the model. Variations in wind direction will limit this effect in areas where the industrial source is located at a distance from the town and the influence of the local source will probably only be significant in towns located downwind, in the direction of the prevailing wind, from the industrial source.

The second assumption can also limit the accuracy of long range predictions. Improvements in air pollution control technology and effective regulation could lower B_e for industrialized cities. Changes in predominant industries could either increase or decrease B_e. For example, increased use of coal fired power plants without adequate pollution controls could result in the increase of B_e over cities, whereas improved control technologies could allow for growth without altering the relationship between urbanization and excess turbidity. The trend analysis described previously for New York City may be an example where improvements in pollution controls have lowered $\overline{B}_e$, but the reduction could also be due to industries and people moving away from the central city.

SECTION 5

REGIONAL STUDIES

INTRODUCTION

Air pollution increasingly has assumed a regional impact role. A variety of assessments have been made of regional or "air mass" pollutant situations, e.g. see: Husar, et al. (1976); Hall, et al. (1973); Peterson, et al. (1981); or Flowers, et al. (1969). Air masses in which dispersion is reduced and pollutant accumulation is favored by low winds, subsidence and nocturnal inversions, and a trajectory over major urban and industrial areas have been shown to develop reduced visibility patterns and conditions of increased turbidity. It is the increased general frequency of conditions of this type that is used as at least a partial explanation of the relative maximum in turbidity values shown by the climatological turbidity data to occurr in the southeastern states and southern Appalachian Mountains.

In the present research the single station analyses of turbidity and air mass conditions such as done by Peterson, et al. (1981) for Raleigh, NC has been extended to regional sets of stations in an attempt to assess the turbidity conditions in air pollution episode-type conditions--those conditions classed by Husar as air mass "blobs." The meteorologist will recognize these situations as slow moving, warm anticyclones. The results of our study have not been completely successful because of limitations in the available data, as will be apparent from the following discussion.

TURBIDITY IN A SLOW MOVING ANTICYCLONE

In an attempt to assess regional turbidity during conditions of relatively high air pollution, time periods were sought which had both a high proportion of turbidity network observations for several days at a time and a high air pollution potential weather pattern--namely a slow moving anticyclone over the eastern part of the United States. With such data it was hoped that the movement of the pollutant air mass could be tracked across the turbidity station network. No time period was found with a really good combination of observational data and synoptic weather. The usual problem was a very spotty observational record with large breaks in all the station records. This could be due to cloud interference or to the problems of a low priority observation.

As a substitute we decided to investigate one anticyclonic haze incident that has been investigated in some detail, namely the period of June 25, to July 5, 1975. During this time a large air mass formed and

moved slowly across the Ohio Valley, recirculated over the area and then moved across the southeastern states and over the Atlantic Ocean. This situation has been investigated in terms of regional visibility and aerosol chemistry by Husar, et al. (1976). During this time period the studies of Husar showed that the general flow across the Ohio Valley and midwest was blocked by a tropical storm "Amy" that moved northward off the United States east coast. During this storm passage west to east air mass movement over much of the area east of the Mississippi River was disrupted and a large air mass with significant visible haze and air pollutant levels developed. Within this air mass 850 mb wind trajectories showed that during the first days of this episode, June 25-27, 1975, the general flow was from the south and that the initial hazy air mass developed in air that had moved in from the Gulf of Mexico. During the period of June 28-30 anticyclonic flow had become centered in the Great Lakes area and the hazy air mass recirculated back over the Ohio Valley and midwest from east to west. Noon visibilities over large areas within the air mass were less than 3 miles from June 27 through the end of the episode. From July 1 to July 3 this low visibility air mass affected much of the upper midwest while the circulation within the anticyclone continued. Flow from the northwest began to be evident on July 3 and by July 5 the episode ended as the air mass and its accumulated air pollutants and haze crossed Georgia and the southeast states and moved over the ocean. Visibilities were less than 4 mi at Atlanta, Tallahassee, and other stations in the southeast when the air mass crossed the area on its trajectory toward the Atlantic.

During this air mass haze episode there were a number of network turbidity stations that were within the affected area. Table 4 shows the turbidity data from stations in the haze air mass area for the period June 23 to July 7, 1975. The stations are listed in 4 general geographic groups -- Appalachians, upper midwest, Ohio Valley, and east coast. Daily averages for the geographic groups are also shown. The very spotty nature of the data set is quite evident in this tabulation. This sort of broken data record is very characteristic of the turbidity record.

The upper midwest area with turbidity measurements at 4 stations, St. Cloud, MN; Bismarck, ND; Huron, SD; and Green Bay, WI; shows some impact of the air mass haze cloud between June 30 and July 3. This was the time period when easterly and southerly flow recirculated the air mass through the upper midwest. Huron and Bismarck while exhibiting turbidity values above summer average values (see Figure 7) did not experience conditions as high as most other stations. The conditions at Green Bay were generally higher than the other stations, as might be expected because of its location closer to the main industrial source regions.

Two of the network stations, Toledo, Ohio; and Youngstown, Ohio were classed as an Ohio Valley group. Data are not available until June 29 for these stations so the initial days of the haze episode are not documented. The highest average concentrations for these 2 stations was on June 29 which is the day the air mass began its recirculation motion with flow from east to west across the Great Lakes-Ohio Valley area. Although both of these stations are in general higher than the upper midwest group of stations the individual turbidity values and the average values for the

period are about 0.200, very similar to the long-term summer average for the area shown by Figure 7.

The east coast group of stations extend from Blue Hill, MA, outside of Boston, south to Atlantic City, NJ and Baltimore and College Park, MD. This area was, for the most part, on the edge of the haze air mass until the final trajectory southward toward the coast on July 3 and 4. In general the higher values of turbidity occurred near the end of the air mass period in more or less agreement with accumulation features of the synoptic situation pointed out by Husar, et al. (1976). Turbidity values for Baltimore were significantly higher than most other stations, as might be expected for a major industrial and commercial city. The higher turbidity for Albany, NY on June 27 may have been due to the eastward extension of the haze area early in the episode. According to Figure 6, summertime background turbidity would be expected to be in the range of 0.20 to 0.25; thus, except for Baltimore the east coast stations do not show exceptionally elevated turbidity values. New York City values, although only 2 measurements are available, are in fact noticeably low, 0.068 on July 1 and 0.107 on July 2. These measurements are taken in Rockefeller Plaza at ground level (altitude 27 m) and are only about half the 1975 summer average for New York City shown by Figure 14. No explanation is apparent although the tropical storm off the northeast coast may have had an effect in bringing a clean air mass and deep mixing into the coastal area.

The Appalachian or southeast section was considered to contain a group of 7 stations in the area from North Carolina and Tennessee to Tallahassee in northern Florida. In general this region had the highest turbidity values during the latter part of the period, between July 3 and 5. At this time the North Carolina-Tennessee area had values in the 0.600 to 0.700 range which is about twice as high as the long-term summer average for this area of around 0.30. Farther south, in Meridian, MS and Tallahassee, FL, peak values occurred on July 4. These observations would be in general agreement with the southward trajectory of the haze air mass. Scattered high turbidity values also occurred in the Raleigh, NC area on June 25 and 26. These occurrences seem to be of less than regional scale, however.

DISCUSSION

In the analysis of this summer 1975 episode and other episodes attempts were made to draw meaningful isoline plots of turbidity , but there was little success because of the scattered nature of the record. This feature of the daily observations is clearly evident in Table 4.

The previous discussion of regional conditions indicates apparently that rather significant regional haze episodes, visibility 3 miles or less, may not be well correlated with the network turbidity data in terms of increased turbidity in heavy haze. In the 1975 situation greater than average turbidity occurred in the upper midwest and in the southeast but apparently not in the Ohio Valley in the central part of the anticyclonic episode. Reasons for this situation are not clearly evident but it points up one of the problems that may occur in evaluating turbidity and

Table 4. Daily Turbidity Coefficient Observations During An Air Pollution Episode - June 25 to July 5, 1975.

Region/Station	June 25	26	27	28	29	30	July 1	2	3	4	5
Midwest											
St. Cloud, MN			.065								
Bismarck, ND			.117			.140	.129				
Huron, SD	.133	.089	.090			.134	.165		.234	.173	
Green Bay, WI	.109			.305		.358				.106	
Average	.121	.089	.091	.305		.211	.147		.234	.140	
(N*)	(2)	(1)	(3)	(1)		(3)	(2)		(1)	(2)	
Ohio Valley											
Toledo, OH					.260	.200	.174	.283		.176	.163
Youngstown, OH					.228	.128	.261	.113			.216
Average					.244	.164	.218	.198	.176	.190	
(N)					(2)	(2)	(2)	(2)	(1)	(2)	
East Coast											
Baltimore, MD	.737					.579	.483	.361	.577		
College Park, MD							.119	.190	.436		
Blue Hill, MA							.170				
Atlantic City, NJ	.613						.113	.123	.270		
Albany, NY			.343			.249		.245		.290	.332
New York, NY							.068	.107			
Upton, NY							.150				
Average	.675		.343			.414	.184	.205	.428	.290	.332
(N)	(2)		(1)			(2)	(6)	(5)	(3)	(1)	(1)

Table 4--(Continued)

Region/Station	June 25	26	27	28	29	30	July 1	2	3	4	5
Southeast											
Tallahassee, FL	.148		.114	.139	.183		.292	.269	.322	.565	
Meridian, MS	.131	.373								.858	
Asheville, NC				.248	.313			.481	.470		
Greensboro, NC	.154							.409	.654		
Raleigh Apt, NC	.422						.222	.165	.619		
Raleigh RTP**, NC		.722					.331	.142	.687		
Oakridge, TN		.116	.092			.398	.577		.687		
Average	.214	.404	.103	.194	.248	.398	.356	.293	.573	.713	
(N)	(4)	(3)	(2)	(2)	(2)	(1)	(4)	(5)	(6)	(2)	

* Number of samples in average
** RTP: Research Triangle Park

visibility data. Perhaps one problem is in the discontinuous and variable record found for most turbidity data and the need for a statistical treatment to smooth over the record variability. The previously calculated climatological data seem to be satisfactory, in this report and in others (e.g., Peterson et al., 1981 or Flowers et al., 1969).

SECTION 6

SUMMARY

A climatological analysis of atmospheric turbidity over the U.S. from 1967 to 1976 and a simple, regionally stratified model relating annual average turbidity to urbanization have been described.

The results of the climatological analysis illustrated the geographical, seasonal, and temporal variations in mean turbidity. Maximum annual average background turbidity occurs over the Southeast and the Smoky Mountain region and minimum annual average background turbidity occurs over the Rocky Mountains and the Interior Southwest. This geographical variation was shown to occur in all four seasons. The annual cycle in turbidity was also described. Maximum seasonal average turbidity occurs in the summer and minimum seasonal average turbidity occurs in the winter in all regions of the U.S. The amplitude of this annual cycle was shown to be greatest over the Southeast and smallest over the Rocky Mountain region.

Results also indicated increases in turbidity, especially in the summer season, over the Southeast and the Smoky Mountain region since the early 1960's. Increasing urbanization and industrialization in the South are suggested as possible causes for this trend.

To develop a simple, regionally stratified model relating turbidity to urbanization, climatological average turbidity was treated as the sum of two terms, background and excess average turbidity. The relationship between urban population and excess average turbidity was shown to be linear and well correlated ($r = 0.76$). The application of this relationship to predict increases in annual average turbidity based on population growth projections for urban areas was also described.

The technique of separating long term average values into background and local effects may be useful in predictive investigations of other properties of the atmosphere, such as visibililty, which are influenced by man's activity.

Regional case studies of turbidity conditions during air pollution episodes were attempted with only marginal results because of the fragmented nature of the turbidity record at most stations. Some air mass transport could be hypothesized from the turbidity data as long as visibility records were available for guidance. These poor regional results were in contrast to some single station records that have been published showing day-to-day turbidity changes at a given location.

REFERENCES

Altshuller, A. P. 1980. Seasonal and Episodic Trends in Sulfate Concentrations (1963-1978) in the Eastern United States. Environ. Sci. and Tech., 14:1337-1349.

Adams, D. R., S. O. Farwell, M. R. Pack, and E. Robinson. 1980. Biogenic Sulfur Gas Emissions from Soils in Eastern and Southeastern U.S. Paper 80-40.5, Annual Meeting, Air Pollution Cont. Assoc., Montreal, June 1980.

Ångström, A. 1961. Techniques of Determining the Turbidity of the Atmosphere. Tellus, XIII:214-223.

Ångström, A. 1963. The Parameters of Atmospheric Turbidity. Tellus, XVI:64-75.

Berri, G. J., and J. T. Peterson. 1978. Dependence of Atmospheric Turbidity at Raleigh, N.C. on Air Mass Trajectories. NOAA Technical Memorandum ERL-ARL-68.

Covert, D. S., R. J. Charlson, and N. C. Ahlquist. 1972. A Study of the Relationship of Chemical Composition and Humidity to Light Scattering by Aerosols. J. Appl. Meteorol., 11:968-976.

Eltermann, L. 1964. Atmospheric Attenuation Model, 1964, in the Ultraviolet, Visible, and Infrared Regions for Altitudes to 50 km. Environmental Research Paper No. 46, AFCRL 64-740, Bedford, MA., Air Force Cambridge Research Laboratories. 40 pp.

Flowers, E. C., R. A. McCormick, and K. R. Kurfis. 1969. Atmospheric Turbidity Over the United States, 1961-1966. J. Appl. Meteorol., 8:955-962.

Hall, F. P., Jr., C. E. Duchon, L. G. Lee, and R. R. Hagan. 1973. Long-range Transport of Air Pollution: A Case Study, August, 1970. Mon. Wea. Rev., 101:404-411.

Husar, R. B., N. V. Giliani, J. D. Husar, C. C. Paley, and P. N. Turcu. 1976. Long-range Transport of Pollutants Observed through Visibility Contour Maps, Weather Maps and Trajectory Analysis. Proceedings, Third Symposium Atmospheric Turbulence, Diffusion, and Air Quality, Raleigh, NC, October, 19-22, 1976, American Meteorol. Soc., Boston, MA.

Husar, R. B., D. E. Patterson, J. M. Holloway, W. E. Wilson, and T. G. Ellestad. 1979. Trends of Eastern U.S. Haziness Since 1948. Proceedings of the Fourth Symposium on Atmospheric Turbulence, Diffusion and Air Pollution, American Meteorological Society, Boston, MA. pp. 249-256.

Huschke, R. E. 1959. Glossary of Meteorology. Am. Meteorol. Soc., Boston, Mass. 638 pp.

Kasten, F. 1964. A New Table and Approximation Formula for the Relative Optical Air Mass. U.S. Army Material Command Technical Report 136.

Korshover, J. 1967. Climatology of Stagnating Anticyclones East of the Rocky Mountains, 1936-1965. U.S. Public Health Service Pub. No. 999-AP-34, Cincinnati, Ohio.

McCormick, R. A. and D. M. Baulch. 1962. The Variation with Height of the Dust Loading Over a City as Determined From the Atmospheric Turbidity. J. Air Pollut. Contr. Assoc., 12:492-496.

McCree, K. J., and M. E. Keener. 1974. Effect of Atmospheric Turbidity on the Photosynthetic Rates of Leaves. Agricultural Meteorology, 13: 349-357.

Minzer, R. A., K. S. W. Champion, and H. L. Pond. 1959. The ARDC Model Atmosphere, 1959. Air Force Cambridge Research Center, Air Force Surveys in Geophysics, No. 115, Cambridge, MA.

Peterson, J. T., and E. C. Flowers, 1977. Interactions Between Air Pollution and Solar Radiation. Solar Energy, 19:23-31.

Peterson, J. T., and E. C. Flowers. 1978. Atmospheric Turbidity over the Los Angeles Basin. J. Appl. Meteorol., 17:528-435.

Peterson, J. T., E. C. Flowers, G. J. Berri, C. L. Reynolds, and J. H. Rudisill. 1981. Atmospheric Turbidity over Central North Carolina. J. Appl. Meteorol., 20:229-241.

Peterson, J. T., E. C. Flowers, and J. H. Rudisill. 1978. Urban-rural Solar Radiation and Atmospheric Turbidity Measurements in the Los Angeles Basin. J. of Appl. Meteorol., 17:1595-1609.

Reisinger, L. M.,and I. L. Crawford. 1980. Sulfur Measurements - South-eastern U.S. Paper 80-40.6, Annual Meeting, Air Pollution Cont. Assoc., Montreal, June 1980.

Trijonis, J., and K. Yuan. 1978. Visibility in the Northeast: Long-Term Visibility Trends and Visibility/Pollutant Relationships. Environmental Protection Agency, Research Triangle Park, NC, EPA-600/3-78-075.

Trijonis, J. 1979. Visibility in the Southeast - an Exploration of the Historical Data Base. Atmos. Environ., 13:833-843.

U.S. Department of Health, Education, and Welfare, Public Health Service, National Center for Air Pollution Control. 1967, 1968, 1969, 1970. Atmospheric Turbidity Report, Cincinnati, Ohio.

Volz, F. 1959. Photometer mit Selen-Photoelement zur Spektralen Messung der Wellenlang-Genabhangigkeit der Dunsttrubung. Archiv fur Meteorologie, Geophysik, und Bioklimatologie, B10:100-131.

WMO-EPA-NOAA. 1971. Atmospheric Turbidity Data for the World. Environmental Data Service, NOAA, Asheville, NC.

WMO-EPA-NOAA. 1972, 1973, 1974. Atmospheric Turbidity and precipitation Chemistry for the World. National Climatic Center, Asheville, NC.

WMO-EPA-NOAA. 1975, 1976. Global Monitoring of the Environment for Selected Atmospheric Constituents. National Climatic Center, Asheville, NC.

APPENDIX A

DETAILED PRESENTATION OF THE TURBIDITY COEFFICIENT AND ITS CALCULATION

BEER'S LAW

The atmospheric attenuation for a specified wavelength of the direct solar beam can be expressed in the Beer's law relationship

$$I_\lambda = I_{o,\lambda}\, 10^{-(S_{p,\lambda} + A_{p,\lambda} + S_{g,\lambda} + A_{g,\lambda})m} \qquad (1)$$

where I_λ is the monochromatic intensity which reaches the earth's surface, $I_{o,\lambda}$ is the intensity just before the beam enters the atmosphere at the mean sun-earth distance, $S_{p,\lambda}$ and $A_{p,\lambda}$ are the wavelength specific, vertical transmission, scattering and absorption coefficients, respectively, for particles, $S_{g,\lambda}$ and $A_{g,\lambda}$ are the vertical transmission scattering and absorption coefficients, respectively, for gases, and m is the relative optical air mass. The standard choice of base ten for the exponential terms is arbitrary. Angstrom (1961 and 1963) presents a detailed discussion of turbidity parameters.

The atmospheric turbidity coefficient (B_λ) at 500 nm, green light near the peak intensity wavelength for visible solar radiation reaching the earth's surface, is defined as the sum of the particle absorption and scattering coefficients, thus

$$B_{500} = S_{p,500} + A_{p,500}. \qquad (2)$$

In turbidity equations, the term for Rayleigh scattering ($S_{g,500}$) is usually symbolized by R and the term for gaseous absorption ($A_{g,500}$) is usually symbolized by Z (for ozone, the only significant gaseous absorber at 500 nm). Employing this nomenclature, substituting Eq. (2) into Eq. (1), and dropping the wavelength subscript (500 nm is now implied) gives the conventional turbidity equation,

$$I = I_o\, 10^{-(R + Z + B)m}. \qquad (3)$$

At 500 nm the dimensionless constants R and Z have the values 0.063 and 0.005, respectively (Eltermann, 1964). Figure A-1 shows the transmission of the 500 nm component of the direct incoming solar beam predicted by Eq. (3) as a function of the atmospheric turbidity (B_{500}) and the solar elevation angle (γ). The relative optical air mass, m, is a function of γ.

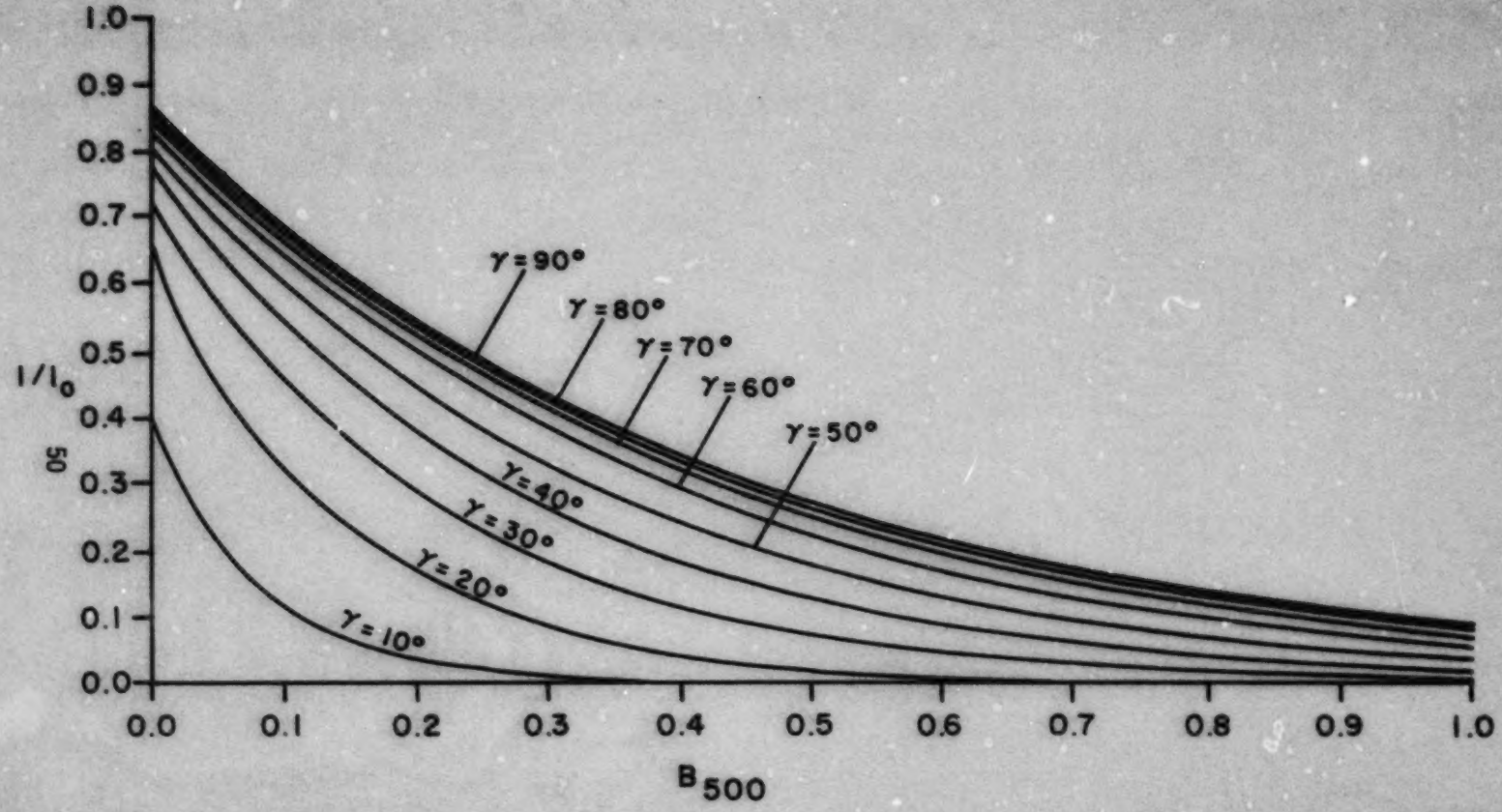


Figure A-1. Beer's law transmission of the direct beam at 500 nm (curves shown are for sea level and the mean sun-earth distance).

Figure A-1 applies to observations at sea level and at the mean sun-earth distance. Correction terms for these variables are discussed below.

Figure A-1 shows that, for a Rayleigh atmosphere (B_{500}=0) and for vertical incidence (γ=90°), Beer's law predicts 86% transmission of the direct beam at 500 nm. For a turbidity coefficient of 0.1 this transmission is reduced to about 70% and for turbidity of 0.3 it is reduced to less than 50%. Furthermore, the decrease in transmission for a given change in turbidity, $d(I/I_0)/dB$, is greater at low turbidities than at high turbidities and this effect is more pronounced at low solar elevations than at high ones. This illustrates that a small change in turbidity has a greater effect on the optical quality of a cleaner atmosphere than it does on an atmosphere which is already heavily laden with particles.

OPTICAL AIR MASS

The relative optical air mass, m, corrects the coefficients Z, R, and B from vertical incidence (γ=90°) to the actual solar elevation at the time of measurement. Values of B derived from Eq. (3) are thus corrected to vertical solar elevation. This standardizes turbidity values and permits comparison of turbidity measurements made at different solar elevation angles, i.e. at different times of the day or in different seasons.

The ratio of the mass of air a beam of light passes through at the solar elevation of observation to the mass of air a beam passes through at vertical incidence is m. The geometry of the optical air mass for atmospheric turbidity is shown in Figure A-2. The relative optical air mass is evaluated according to the expression

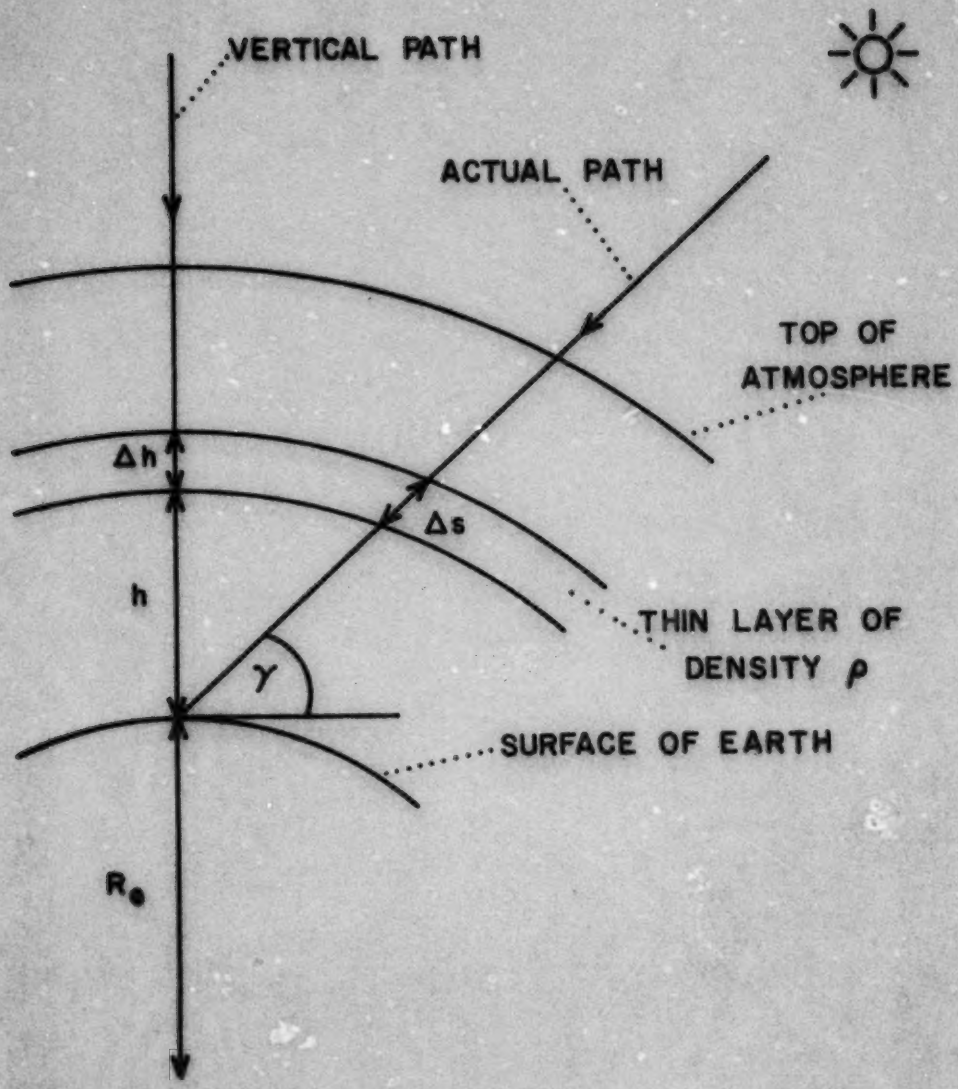
$$m = \frac{\int_0^\infty \rho \, ds}{\int_0^\infty \rho \, dh} \qquad (4)$$

where dh is a path element of the vertical transit and ds is a path element of the transit at solar elevation γ. For a plane parallel atmosphere ds = dh/sinγ so Eq. (4) reduces to

$$m = 1/\sin\gamma, \qquad (5)$$

which is accurate within 0.1% for solar elevations above 30°. However, the curvature of the earth and the refractive properties of the atmosphere make Eq. (5) increasingly inaccurate as the solar elevation angle decreases. Considering the curvature of the earth and atmosphere and employing finite difference notation, the exact relationship between Δs and Δh becomes

$$\Delta s = \frac{(R_e+h)(R_e+h+\Delta h)\sin\left(\arcsin\left(\frac{R_e\cos\gamma}{R_e+h}\right) - \arcsin\left(\frac{R_e\cos\gamma}{R_e+h+\Delta h}\right)\right)}{R_e\cos\gamma} \qquad (6)$$



GEOMETRY OF OPTICAL AIR MASS

Figure A-2. Geometry of optical air mass.

where the symbols have the meanings shown in Figure A-2. Substituting this value for Δs into Eq. (4) and choosing a suitable step-width for Δh permits numerical determination of m, considering curvature, for a standard atmospheric density profile.

Kasten (1964) developed a numerical solution of Eq. (4) which allows for both curvature and refraction. Based on the U.S. Air Force Model Atmosphere density profile (Minzner, et al., 1959) and choosing 84 km as an upper limit for the integration. Kasten developed the approximation formula

$$m = \frac{1}{\sin\gamma + a(\gamma+b)^{-c}} \tag{7}$$

where a = 0.1500, b = 3.855, c = 1.253, and γ is in degrees. Above 84 km the air density is so low that additional attenuation is negligible. Eq. (7) is used to determine m for atmospheric turbidity calculations.

CORRECTION TERMS

Two correction factors, one for the elliptical nature of the earth's orbit about the sun and the second for the height of the observation site above sea level, must be applied to Eq. (3). Since the earth's orbit about the sun is slightly elliptical the radiation intensity (I_o) at the top of the atmosphere varies with time. There is a difference of approximately 6% in I_o between aphelion and perihelion. Correction for the altitude of the observation site is required because Rayleigh (gaseous) scattering for incoming solar radiation decreases in proportion to the decrease in pressure for elevated sites. When these correction factors are included, Eq. (3) becomes

$$I = I_o \left(\frac{\bar{r}}{r}\right)^2 10^{-(R(P/P_o) + Z + B)m} \tag{8}$$

where r and $\bar{r}$ are the actual and mean sun-earth distances, respectively, and P and P_o are the station and sea level pressures, respectively.

Solving Eq. (8) for B gives the working equation for turbidity determination:

$$B = \frac{-1}{m} \log_{10}\left(\frac{I}{I_o \left(\frac{\bar{r}}{r}\right)^2}\right) - (R(P/P_o) + Z) \tag{9}$$

In practice, J, the sun photometer reading, and J_o, the instrument calibration coefficients, are substituted for I and I_o, respectively.

A sample calculation of B is given in the following section.

SAMPLE TURBIDITY CALCULATION

Required Input:

Station: Blue Hill, MA

Date: 12/2/70

Time of observation: 1157 EST (Time Zone 5)

Latitude: 42.13°N

Longitude: 71.07°W

$J_{o,500} = 63.0$

$J_{500} = 23.5$

$(\frac{\bar{r}}{r}) = 0.97$

Height of station: 198 m

Find Optical Air Mass (m):

A. From Longitude, Latitude, Date, Local Time, and Time Zone calculate solar elevation angle: $\gamma = 25.65°$

B. Apply Kasten's approximation formula (equation 7) to find m:

$$m = \frac{1}{\sin\gamma + .15\ (\gamma + 3.855)^{-1.253}} = 2.2987$$

Correct Rayleigh Term for Height of Station:

A. Apply hydrostatic equation or pressure reduction formula to find $P/P_o = 0.9987$.

B. Apply correction:

$P/P_o\ R = (0.9987)(0.0630) = 0.0629$

SAMPLE TURBIDITY CALCULATION (Continuted)

Substitute into Working Turbidity Equation (Equation 9):

$$B = \frac{-\log_{10} \frac{23.5}{(63.0)(0.97)}}{2.2987} - (0.004 + 0.0629)$$

B = 0.114 (turbidity coefficient for 500 nm)

APPENDIX B

SUMMARY OF DATA FOR REGIONALLY STRATIFIED MODEL

APPENDIX B. Summary of data for regionally stratified model.

Site	$\bar{B}_{measured}$	$\bar{B}_b$	$\bar{B}_e$*	Population	$\bar{B}_{model}$
Mount Hopkins, AZ (5)**	0.0453	0.045	0.0003	2,500+	0.0547
Tucson, AZ (1)	0.0707	0.050	0.0207	298,693	0.0714
Little Rock, AR (9)	0.1719	0.100	0.0719	139,703	0.1151
Bishop, CA (4)	0.0625	0.061	0.0024	2,500+	0.0707
Los Angeles, CA (1)	0.2553	0.120	0.1353	2,809,813	0.2413
San Jose, CA (4)	0.0955	0.085	0.015	445,779	0.1123
San Francisco, CA (2)	0.1233	0.085	0.0383	715,674	0.1230
Edwards Air Force Base, CA (1)	0.0802	0.078	0.0032	2,500+	0.0877
Pittsburg, CA (2)	0.0923	0.085	0.0073	20,651	0.0954
Redwood City, CA (2)	0.0851	0.085	0.0001	55,686	0.0968
Richmond, CA (3)	0.1367	0.085	0.0517	397,358++	0.1104
San Bernardino, CA (3)	0.1770	0.110	0.0670	1,456,058++	0.1755
Alamosa, CO (5)	0.0701	0.060	0.0101	6,985	0.0693
Boulder, CO (3)	0.0582	0.050	0.0082	66,870	0.0622
Washington, DC (2)	0.1372	0.136	0.001	756,510	0.1756
Gainesville, FL (1)	0.1392	0.129	0.01	64,510	0.1411
Miami, FL (3)	0.1143	0.110	0.0043	334,859	0.1329
Tallahassee, FL (4)	0.1528	0.045	0.0128	72,624	0.1525
Idaho Falls, ID (5)	0.0405	0.095	0	37,126	0.0560
Chicago, IL (2)	0.1867	0.100	0.0917	3,366,957	0.2384
Salem, IL (2)	0.1109	0.084	0.0109	6,359	0.1098
Topeka, KS (8)	0.0741	0.075	0	125,011	0.0986
Caribou, ME (5)	0.0781	0.135	0.0031	10,419	0.0849
Baltimore, MD (8)	0.2402	0.135	0.1052	905,759	0.1806
Beltsville, MD (5)	0.1376	0.075	0.0026	8,912	0.1449
College Park, MD (7)	0.1513	0.135	0.0164	26,156	0.1456
Blue Hill, MA (8)	0.1244	0.105	0.0194	2,500+	0.1147

APPENDIX B--(Continued)

Site	$\bar{B}_{measured}$	$\bar{B}_b$	$\bar{B}_e$*	Population	$\bar{B}_{model}$
Saint Cloud, MN (8)	0.0785	0.079	0.0005	40,715	0.0902
Meridian, MS (9)	0.1283	0.130	0	46,087	0.1414
Kansas City, MO (1)	0.1461	0.085	0.0611	507,330	0.1147
Saint Louis, MO (7)	0.1134	0.095	0.0184	622,236	0.1293
Missoula, MT (9)	0.0631	0.052	0.0111	29,497	0.0627
Atlantic City, NJ (5)	0.1454	0.128	0.0174	47,859	0.1395
Albuquerque, NM (2)	0.0516	0.048	0.0036	243,751	0.0673
Los Alamos, NM (5)	0.0361	0.0361	0	11,310	0.0461
Albany, NY (7)	0.1811	0.1170	0.0641	115,781	0.1311
Rockefeller Plaza, NY (9)	0.1549	0.118	0.0369	1,539,233	0.1887
Upton, NY (7)	0.1352	0.106	0.0292	2,500+	0.1157
Raleigh, NC (4)	0.1550	0.135	0.0200	125,793	0.1496
Asheville, NC (3)	0.1405	0.159	0	57,681	0.1709
Greensboro, NC (9)	0.1410	0.140	0.0010	144,076	0.1553
Bismarck, ND (4)	0.0717	0.07	0.0017	38,123	0.0811
Columbus, OH (1)	0.1195	0.118	0.0015	540,025	0.1490
Cincinnati, OH (1)	0.1384	0.119	0.0194	451,455	0.1465
Toledo, OH (8)	0.1073	0.100	0.0073	383,105	0.1248
Youngstown, OH (9)	0.1305	0.119	0.0115	140,909	0.1342
Pendleton, OR (4)	0.0588	0.058	0.0008	13,197	0.0681
Philadelphia, PA (3)	0.2907	0.125	0.1657	1,949,996	0.2121
Huron, SD (8)	0.0767	0.074	0.0027	14,299	0.0842
Memphis, TN (8)	0.1736	0.117	0.0566	623,536	0.1514
Oak Ridge, TN (7)	0.1735	0.164	0.0095	28,319	0.1747
Grand Prairie, TX (5)	0.1177	0.090	0.0277	447,652++	0.1016
Seattle, WA (1)	0.1489	0.084	0.0600	530,831	0.1147
Elkins, WV (6)	0.1598	0.141	0.0188	8,287	0.1509
Green Bay, WI (9)	0.0909	0.087	0.0039	88,304	0.1001

* $\bar{B}_e = (\bar{B}_{measured} - \bar{B}_b)$

** Parenthesized numbers represent the number of years data adequacy requirements were met for calculation of $\bar{B}$ measured.

\+ Remote and background sites in towns of 2,500 or less are arbitrarily plotted at 2,500.

++ Effective population, corrected for influence of neaby urban center.

APPENDIX C

TABULATION OF TURBIDITY ANNUAL AVERAGES AND SEASONAL AVERAGES
BY YEARS - 1967-1976,
UNITED STATES TURBIDITY NETWORK STATIONS

Footnotes applicable to all Appendix C Tables:

(1) Number of observations may exceed 1 per day
(2) **** indicates no turbidity observations
(3) All 1977 data should be disregarded, it shows in the tabulation because December, 1976 is included in the 1977 winter average.
(4) See report reference list for primary source references, i.e. WMO and EPA publications.

SITE: MOUNT HOPKINS, ARIZONA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1969	.004	1	8	****	0	****	0	****	0	.004	8
1970	.045	11	315	.027	80	.040	130	.088	42	.044	63
1971	.017	11	223	.013	55	.013	85	.027	22	.027	61
1972	.045	6	85	.021	60	****	0	.075	10	.065	15
1973	.055	11	135	.036	19	.070	29	.076	46	.037	41
1974	.056	12	77	.035	27	.060	29	.074	15	.046	6
1975	.055	11	75	.034	13	.065	20	.070	27	.048	15
1976	.062	4	26	****	0	.060	11	.060	15	****	0

SITE: TUCSON, ARIZONA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.071	10	446	.051	27	.078	118	.094	145	.049	156
1968	.043	1	21	.043	21	****	0	****	0	****	0

SITE: LITTLE ROCK, ARKANSAS

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.162	11	107	.115	21	.178	31	.179	16	.146	39
1968	.121	6	58	.093	9	****	0	.136	3	.137	46
1969	.157	12	125	.090	23	.186	34	.210	41	.125	27
1970	.159	12	88	.118	26	.169	23	.227	23	.146	16
1971	.180	12	87	.100	22	.177	26	.252	22	.153	17
1972	.186	12	122	.121	24	.197	34	.257	40	.164	24
1973	.166	12	99	.105	20	.170	21	.239	24	.176	34
1974	.174	11	101	.116	27	.202	25	.228	22	.138	27
1975	.190	12	96	.136	23	.203	22	.240	20	.184	31
1976	.174	12	136	.114	27	.203	37	.245	34	.130	38
1977	.098	1	24	.098	24	****	0	****	0	****	0

SITE: BISHOP, CALIFORNIA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1972	.052	12	620	.033	135	.067	178	.070	190	.044	117
1973	.045	10	310	.025	74	.050	92	.064	138	.037	6
1974	.057	9	515	****	0	.051	147	.067	212	.057	156
1975	.082	12	597	.048	104	.101	120	.112	200	.069	173
1976	.071	12	465	.050	115	.100	118	.081	165	.052	67
1977	.034	1	12	.034	12	****	0	****	0	****	0

SITE: LOS ANGELES, CALIFORNIA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.255	9	243	.273	14	.219	54	.270	150	.303	25

SITE: GOLETA, CALIFORNIA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.155	11	181	.087	34	.179	74	.198	39	.155	34
1968	.020	1	1	.020	1	****	0	****	0	****	0

SITE: PASADENA, CALIFORNIA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1971	.190	2	198	****	0	****	0	.190	198	****	0

SITE: SAN JOSE, CALIFORNIA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.127	11	280	.121	38	.127	62	.142	86	.121	94
1968	.112	6	167	.071	25	****	0	.131	68	.120	74
1969	.114	12	337	.084	48	.143	101	.139	95	.093	93
1970	.080	9	277	.056	15	.075	90	.075	104	.095	68
1971	.062	9	289	.056	22	.081	77	.048	118	.054	72
1972	.058	7	148	.065	37	.056	66	.057	45	****	0

SITE: SAN FRANCISCO, CALIFORNI

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.123	11	183	.148	28	.111	64	.119	51	.134	40
1968	.105	6	53	.078	11	****	0	.126	17	.114	25
1969	.124	10	119	.145	5	.141	67	.149	26	.079	21
1971	.075	2	10	****	0	.075	10	****	0	****	0
1972	.097	7	34	.083	7	.114	10	.094	17	****	0

SITE: EDWARDS AB, CALIFORNIA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1974	.050	1	48	****	0	****	0	****	0	.050	48
1975	.080	10	527	.046	61	.109	82	.087	211	.081	173
1976	.067	7	272	.051	10	.100	18	.074	112	.052	132
1977	.046	1	50	.046	50	****	0	****	0	****	0

SITE: ALBANY HILL, CALIFORNIA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1968	.080	3	31	****	0	****	0	.082	20	.091	11
1969	.094	11	109	.065	6	.117	38	.094	36	.087	29
1970	.077	1	8	.077	8	****	0	****	0	****	0

SITE: PORT CHICAGO, CALIFORNIA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.115	10	109	.076	19	.123	25	.135	26	.118	39
1968	.101	6	75	.062	6	****	0	.123	33	.109	36
1969	.067	1	12	.067	12	****	0	****	0	****	0

SITE: PITTSBURG, CALIFORNIA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1969	.119	11	117	.071	12	.131	33	.132	38	.119	34
1971	.100	6	40	.078	6	****	0	.090	10	.114	24
1972	.065	11	139	.062	10	.073	40	.058	59	.073	30
1973	.029	1	3	.029	3	****	0	****	0	****	0

SITE: REDWOOD CITY, CALIFORNIA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1968	.121	5	160	****	0	****	0	.138	67	.117	93
1969	.113	12	199	.098	48	.145	54	.087	50	.090	47
1970	.069	9	127	.075	5	.063	40	.064	55	.083	27
1971	.057	9	71	.049	12	.058	19	.043	30	.063	10
1972	.057	10	46	.071	13	.054	15	.036	12	.085	6

SITE: RICHMOND, CALIFORNIA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.115	11	155	.096	21	.112	60	.122	42	.135	32
1968	.093	3	31	.074	4	****	0	****	0	.108	27
1969	.133	12	124	.088	28	.148	37	.157	38	.128	21
1971	.162	10	67	.082	3	.151	13	.164	33	.222	18
1972	.241	1	4	****	0	.241	4	****	0	****	0

SITE: SAN RAFAEL, CALIFORNIA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1968	.150	5	63	****	0	****	0	.159	26	.149	37
1969	.102	1	5	.102	5	****	0	****	0	****	0
1971	.113	2	12	.096	7	.129	5	****	0	****	0

SITE: SAN BERNARDINO, CALIFORN

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1968	.119	5	63	****	0	****	0	.164	27	.088	36
1969	.135	12	137	.082	33	.171	36	.184	40	.082	28
1970	.158	12	128	.099	23	.131	38	.249	42	.168	25
1971	.238	12	137	.117	25	.295	26	.337	45	.196	41
1972	.315	8	93	.196	34	.362	31	.424	28	****	0

SITE: ALAMOSA, COLORADO

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1972	.091	12	514	.061	166	.124	156	.119	118	.054	74
1973	.050	11	470	.029	137	.053	84	.071	144	.042	105
1974	.073	10	372	.030	12	.092	110	.088	131	.061	119
1975	.072	12	407	.049	96	.086	81	.095	143	.058	87
1976	.065	12	128	.040	30	.079	29	.082	24	.058	45
1977	.041	1	12	.041	12	****	0	****	0	****	0

SITE: BOULDER, COLORADO KB

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1975	.044	4	305	****	0	****	0	.059	99	.042	206
1976	.026	1	99	.026	99	****	0	****	0	****	0

SITE: BOULDER, COLORADO, NCB

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1975	.032	3	263	****	0	****	0	.037	99	.032	164
1976	.016	1	26	.016	26	****	0	****	0	****	0

SITE: BOULDER, COLORADO

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1968	.026	5	149	****	0	****	0	.035	51	.024	98
1969	.038	9	221	.024	73	.045	67	.062	58	.014	23
1970	.070	12	280	.017	53	.060	63	.162	96	.026	68
1971	.047	11	168	.011	54	.041	32	.083	35	.042	47
1972	.023	6	45	.016	22	.029	3	.031	20	****	0
1973	.049	4	40	****	0	****	0	.055	35	.025	5
1974	.039	5	28	.027	14	.056	14	****	0	****	0

SITE: UCAR BOULDER, COLORADO

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.047	11	473	.048	22	.055	127	.058	151	.030	173
1968	.025	1	20	.025	20	****	0	****	0	****	0

SITE: DENVER, COLORADO

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1968	.070	4	61	****	0	****	0	.077	16	.069	45
1969	.059	2	15	.057	15	****	0	****	0	****	0

SITE: WASHINGTON, D. C.

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.143	11	279	.098	51	.124	72	.208	59	.142	97
1968	.115	6	130	.072	18	****	0	.167	49	.098	63
1969	.131	12	229	.091	42	.134	76	.169	42	.102	69
1970	.222	9	117	.067	15	.199	6	.408	53	.162	43
1971	.114	9	236	.086	55	.116	121	.139	60	****	0

SITE: GAINESVILLE, FLORIDA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1973	.139	11	354	.087	70	.109	123	.200	88	.135	73
1974	.095	5	104	.069	73	.143	31	****	0	****	0
1975	.069	1	28	****	0	****	0	****	0	.069	28
1976	.087	5	128	.072	85	.140	26	****	0	.079	17
1977	.054	1	8	.054	8	****	0	****	0	****	0

SITE: MIAMI, FLORIDA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.131	9	33	.119	3	.122	13	.197	3	.115	14
1972	.077	1	28	****	0	****	0	****	0	.077	28
1973	.108	12	250	.087	52	.119	81	.122	51	.105	66
1974	.100	9	156	.107	49	.134	13	.099	41	.081	53
1975	.114	12	215	.088	73	.126	41	.136	49	.105	52
1976	.122	12	262	.088	61	.139	82	.139	63	.117	56
1977	.110	1	8	.110	8	****	0	****	0	****	0

SITE: TALLAHASSEE, FLORIDA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1973	.163	11	.219	.070	42	.097	57	.289	42	.124	78
1974	.137	12	289	.092	61	.111	73	.224	35	.100	120
1975	.153	12	292	.082	75	.156	71	.206	51	.124	95
1976	.157	12	311	.093	126	.139	74	.266	50	.138	61
1977	.088	1	25	.088	25	****	0	****	0	****	0

SITE: GIT ATLANTA, GEORGIA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.144	11	169	.094	23	.133	58	.210	42	.121	46
1968	.059	1	4	.059	4	****	0	****	0	****	0

SITE: IDAHO FALLS, IDAHO

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.044	11	184	.039	38	.051	29	.047	57	.037	60
1968	.054	6	68	.031	4	****	0	.070	28	.055	36
1969	.043	12	184	.041	26	.054	52	.038	83	.036	23
1970	.052	12	140	.034	14	.080	15	.053	60	.041	51
1971	.040	10	59	.024	14	.062	14	.043	25	.022	6
1972	.022	11	50	.022	11	.039	20	.016	11	.008	8
1973	.041	4	44	.038	25	.051	19	****	0	****	0

SITE: CHICAGO, ILLINOIS

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.181	11	137	.169	19	.201	45	.194	43	.159	30
1968	.180	6	78	.142	6	****	0	.242	38	.161	34
1969	.192	12	104	.155	25	.208	32	.260	28	.155	19
1970	.189	8	58	.179	19	.197	24	.202	15	****	0

SITE: SALEM, ILLINOIS

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1972	.110	12	205	.066	67	.142	60	.143	51	.100	27
1973	.112	12	118	.065	37	.130	28	.157	31	.089	22
1974	.108	9	53	****	0	.083	18	.141	10	.105	25
1975	.101	9	52	.096	11	****	0	.121	9	.093	32
1976	.088	7	168	.067	30	****	0	.127	40	.076	98
1977	.045	1	24	.045	24	****	0	****	0	****	0

SITE: TOPEKA, KANSAS

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.076	10	78	.057	22	.082	9	.116	27	.053	20
1968	.062	5	36	.031	6	****	0	.064	9	.108	21
1969	.137	11	59	.037	4	.093	18	.088	7	.184	30
1970	.065	12	119	.045	43	.084	27	.091	31	.043	18
1971	.062	12	122	.041	35	.071	23	.125	23	.046	41
1972	.062	12	128	.034	33	.088	39	.093	38	.052	18
1973	.055	12	97	.034	31	.061	25	.070	25	.035	16
1974	.056	10	69	.037	21	.065	7	.074	13	.043	28
1975	.081	11	61	.034	10	.076	12	.088	24	.071	15
1976	.079	9	66	.123	17	.075	6	.124	14	.043	29
1977	.375	1	10	.375	10	****	0	****	0	****	0

SITE: CARIBOU, MAINE

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1972	.060	12	197	.051	66	.087	53	.051	38	.038	40
1973	.055	12	149	.043	61	.044	33	.094	36	.045	19
1974	.094	12	88	.053	30	.072	29	.159	16	.110	13
1975	.093	12	93	.069	24	.092	26	.134	26	.064	17
1976	.088	12	51	.065	21	.106	11	.128	14	.061	5

SITE: BALTIMORE, MARYLAND

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.204	11	109	.165	18	.203	28	.275	26	.155	37
1968	.221	6	68	.096	8	****	0	.386	27	.163	33
1969	.179	12	124	.084	30	.190	34	.321	30	.122	30
1970	.225	12	128	.132	32	.200	28	.348	43	.244	25
1971	.224	12	151	.144	30	.201	40	.330	45	.222	36
1972	.212	12	145	.125	26	.214	37	.326	45	.185	37
1973	.241	12	160	.146	27	.232	36	.405	56	.190	41
1974	.270	12	137	.135	27	.282	35	.390	35	.286	40
1975	.367	12	143	.220	38	.432	36	.562	40	.271	29
1976	.527	12	135	.330	27	.596	37	.671	35	.504	36
1977	.315	1	12	.315	12	****	0	****	0	****	0

SITE: BELTSVILLE, MARYLAND

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.094	2	25	****	0	****	0	****	0	.094	25
1968	.149	6	45	.099	3	****	0	.220	16	.123	26
1969	.162	12	76	.091	15	.177	24	.209	10	.126	27
1970	.173	12	63	.103	13	.142	14	.323	16	.161	20
1971	.141	12	131	.101	23	.162	47	.222	31	.097	30
1972	.130	12	138	.094	37	.129	45	.184	21	.094	35
1973	.105	11	108	.075	29	.128	25	.130	9	.094	45
1974	.114	12	162	.075	33	.117	45	.163	32	.101	52
1975	.105	5	65	.086	39	.134	26	****	0	****	0

SITE: COLLEGE PARK, MARYLAND

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1969	.108	3	52	****	0	****	0	****	0	.109	52
1970	.154	11	258	.073	45	.125	55	.290	76	.135	82
1971	.128	11	289	.068	68	.097	82	.257	39	.131	100
1972	.142	12	214	.060	68	.104	49	.323	62	.092	35
1973	.163	12	199	.059	39	.105	38	.358	69	.151	53
1974	.170	11	125	.088	19	.167	30	.274	23	.114	53
1975	.146	12	97	.106	14	.134	24	.275	43	.057	16
1976	.157	12	173	.078	31	.135	42	.291	72	.116	28
1977	.109	1	6	.109	6	****	0	****	0	****	0

SITE: BLUE HILL, MASSACHUSETTS

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.112	10	196	.051	33	.094	43	.191	42	.078	78
1968	.088	6	122	.057	18	****	0	.114	51	.090	53
1969	.109	11	239	.074	51	.120	72	.151	28	.105	88
1970	.177	8	108	****	0	.190	30	.213	35	.146	43
1971	.146	12	233	.097	59	.166	52	.197	68	.121	54
1972	.133	11	145	.089	46	.191	34	.236	16	.055	49
1973	.092	12	177	.049	36	.103	35	.137	48	.080	58
1974	.107	12	154	.064	31	.104	44	.160	43	.104	36
1975	.142	12	176	.090	39	.139	45	.209	37	.125	55
1976	.154	11	175	.094	35	.155	36	.215	47	.146	57
1977	.098	1	9	.098	9	****	0	****	0	****	0

SITE: ANN ARBOR, MICHIGAN

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.095	6	39	.094	11	.099	17	.104	11	****	0

SITE: SAINT CLOUD, MINNESOTA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.093	11	342	.073	61	.104	85	.108	97	.087	99
1968	.070	6	185	.050	28	****	0	.091	71	.066	86
1969	.085	12	457	.068	76	.100	160	.104	144	.079	77
1970	.081	12	407	.062	80	.085	93	.105	130	.073	104
1971	.080	12	395	.060	92	.098	123	.101	96	.065	84
1972	.069	9	206	.060	85	****	0	.093	60	.057	61
1973	.068	12	259	.041	60	.081	62	.096	70	.057	67
1974	.073	12	240	.088	56	.076	75	.062	55	.075	54
1975	.081	12	316	.069	77	.093	54	.107	96	.064	89
1976	.067	12	342	.051	64	.076	91	.072	94	.071	93
1977	.046	1	14	.046	14	****	0	****	0	****	0

SITE: MERIDIAN, MISSISSIPPI

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.118	11	452	.071	61	.121	149	.173	100	.083	142
1968	.100	6	232	.068	25	****	0	.135	79	.091	128
1969	.112	12	400	.066	74	.116	108	.157	88	.102	130
1970	.111	12	394	.061	111	.127	92	.173	78	.092	113
1971	.125	12	417	.064	74	.127	133	.180	87	.128	123
1972	.134	12	378	.059	73	.110	108	.213	99	.168	98
1973	.120	12	357	.080	72	.096	97	.190	86	.108	102
1974	.116	12	219	.052	77	.095	61	.203	36	.102	45
1975	.179	12	203	.112	30	.166	37	.267	57	.120	79
1976	.148	12	260	.055	85	.114	59	.309	67	.095	49
1977	.040	1	6	.040	6	****	0	****	0	****	0

SITE: KANSAS CITY, MISSOURI

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.146	11	448	.091	88	.147	90	.191	148	.136	122

SITE: SAINT LOUIS, MISSOURI

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.159	11	455	.112	79	.191	123	.191	153	.139	100
1968	.098	6	177	.072	19	****	0	.155	65	.073	93
1969	.146	12	437	.073	57	.138	116	.242	179	.128	85
1970	.135	12	428	.092	75	.149	107	.182	140	.085	106
1971	.095	12	492	.055	83	.096	137	.149	134	.083	138
1972	.106	12	369	.061	77	.119	92	.149	143	.107	57
1973	.079	12	312	.045	53	.064	83	.139	139	.075	37
1974	.074	12	302	.082	80	.139	131	.031	79	.040	12
1975	.060	1	7	.060	7	****	0	****	0	****	0

SITE: MISSOULA, MONTANA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.068	11	133	.049	11	.082	35	.079	70	.071	17
1968	.084	5	53	****	0	****	0	.076	36	.116	17
1969	.100	12	145	.119	9	.088	31	.090	62	.073	43
1970	.080	12	143	.084	21	.081	32	.085	58	.080	32
1971	.065	10	109	.031	12	.084	25	.068	50	.064	22
1972	.064	12	97	.059	9	.083	23	.059	44	.057	21
1973	.053	12	131	.043	21	.063	38	.069	48	.049	24
1974	.054	12	138	.037	7	.052	19	.055	59	.055	53
1975	.055	12	115	.031	9	.075	19	.074	45	.054	42
1976*	.055	12	151	.049	11	.079	34	.046	58	.047	48
1977	.034	1	2	.034	2	****	0	****	0	****	0

*A few very high turbidity values have been dropped from the 1976 record to give the values shown.

SITE: ATLANTIC CITY, NEW JERSE

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1972	.130	12	318	.068	85	.129	80	.243	69	.097	84
1973	.151	12	281	.057	62	.120	53	.320	86	.127	80
1974	.145	12	277	.084	49	.143	69	.239	60	.116	99
1975	.166	12	249	.104	56	.155	57	.254	62	.135	74
1976	.135	12	286	.093	59	.180	79	.191	74	.079	74
1977	.052	1	34	.052	34	****	0	****	0	****	0

SITE: ALBUQUERQUE, NEW MEXICO

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.047	4	96	****	0	****	0	.062	28	.041	68
1968	.043	5	96	.032	15	****	0	.046	44	.046	37
1969	.061	12	108	.035	32	.079	39	.061	13	.032	24
1970	.042	12	43	.030	6	.055	12	.066	10	.024	15
1972	.081	2	18	****	0	.084	18	****	0	****	0

SITE: LOS ALAMOS, NEW MEXICO

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1969	.025	1	34	****	0	****	0	****	0	.025	34
1970	.038	9	375	.026	124	.052	133	.048	66	.028	52
1971	.040	11	491	.021	101	.045	128	.060	75	.028	187
1972	.037	11	337	.022	65	.042	112	.049	67	.030	93
1973	.033	12	269	.020	71	.040	35	.055	65	.022	98
1974	.034	12	310	.020	79	.038	89	.045	58	.034	84
1975	.049	8	188	.035	75	.054	74	.058	39	****	0
1976	.037	11	277	.023	44	.041	73	.054	74	.027	86
1977	.017	1	32	.017	32	****	0	****	0	****	0

SITE: ALBANY, NEW YORK

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.151	11	187	.084	23	.124	53	.244	50	.137	61
1968	.176	6	134	.096	14	****	0	.270	61	.161	59
1969	.184	12	240	.104	54	.198	60	.277	73	.175	53
1970	.246	12	242	.124	59	.250	74	.387	73	.240	36
1971	.122	1	20	.122	20	****	0	****	0	****	0
1972	.149	11	176	.130	27	.140	65	.235	46	.087	38
1973	.140	12	214	.068	44	.156	32	.224	55	.139	83
1974	.177	12	259	.110	50	.166	107	.258	55	.174	47
1975	.221	12	264	.126	33	.251	106	.300	59	.215	66
1976	.261	7	112	.159	50	.307	49	.371	13	****	0

SITE: ROCKEFELLER PLAZA. NEW Y

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.185	10	229	.148	49	.164	45	.313	32	.151	103
1968	.190	6	143	.094	19	****	0	.253	63	.194	61
1969	.177	12	226	.117	74	.175	82	.253	34	.139	36
1970	.175	12	168	.139	37	.198	47	.238	38	.186	46
1971	.172	11	219	.155	9	.165	79	.181	70	.174	61
1972	.136	12	170	.095	56	.147	50	.214	29	.105	35
1973	.137	12	187	.076	21	.146	48	.230	63	.110	55
1974	.120	12	118	.092	20	.122	29	.188	36	.089	33
1975	.142	12	151	.096	31	.162	48	.162	23	.112	49
1976	.149	12	147	.084	41	.157	36	.202	32	.097	38

SITE: UPTON, NEW YORK

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.127	11	160	.081	22	.098	34	.229	43	.087	61
1968	.137	6	75	.053	12	****	0	.241	38	.102	25
1969	.155	12	117	.077	25	.147	35	.167	33	.298	24
1970	.133	12	92	.083	23	.164	24	.187	25	.133	20
1971	.131	12	101	.085	24	.118	28	.205	26	.128	23
1972	.137	12	66	.096	23	.106	13	.224	10	.056	20
1973	.101	11	34	.075	9	.118	13	.146	2	.102	10
1974	.100	8	23	.073	13	.122	7	****	0	.133	3
1975	.162	11	34	.111	10	.161	12	.218	7	.146	5
1976	.095	2	5	.095	5	****	0	****	0	****	0

SITE: WHITEFACE MTN, NEW YORK

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1970	.139	5	173	****	0	.091	36	.171	137	****	0

SITE: RALEIGH, NORTH CAROLINA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1972	.123	12	993	.055	148	.122	257	.211	297	.106	291
1973	.157	12	955	.053	297	.109	253	.311	280	.107	125
1974	.144	12	1015	.056	258	.114	267	.296	193	.094	297
1975	.190	12	828	.053	281	.157	264	.339	167	.135	116
1976	.053	1	73	.053	73	****	0	****	0	****	0

SITE: RALEIGH, NORTH CAROLINA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1969	.133	5	364	****	0	****	0	.183	98	.092	266
1970	.150	12	1101	.059	297	.121	248	.286	259	.133	297
1971	.157	8	782	.148	297	****	0	.216	188	.126	297
1972	.046	1	31	.046	31	****	0	****	0	****	0
1976	.159	11	573	.056	182	.127	194	.325	77	.090	120
1977	.045	1	55	.045	55	****	0	****	0	****	0

SITE: RALEIGH, NORTH CAROLINA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1972	.133	12	295	.053	70	.115	82	.260	84	.122	59
1973	.042	1	25	.042	25	****	0	****	0	****	0
1974	.151	11	212	.069	23	.117	67	.285	39	.108	83
1975	.208	11	228	.057	40	.185	65	.323	87	.282	36

SITE: RALEIGH, NORTH CAROLINA.

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1972	.041	2	17	.038	17	****	0	****	0	****	0

SITE: ASHEVILLE, NORTH CAROLIN

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1972	.274	6	348	****	0	****	0	.357	178	.204	170
1973	.147	12	872	.096	140	.086	206	.277	232	.127	294
1974	.149	12	1062	.054	203	.104	265	.350	297	.091	297
1975	.131	9	676	.068	262	.126	288	.257	79	.049	47
1976	.125	12	1002	.042	297	.084	245	.274	189	.073	271
1977	.037	1	99	.037	99	****	0	****	0	****	0

SITE: GREENSBORO, NORTH CAROLI

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.127	11	321	.075	45	.115	99	.185	61	.103	116
1968	.122	6	117	.054	15	****	0	.208	37	.087	65
1969	.135	12	251	.063	48	.137	80	.237	68	.105	55
1970	.145	12	218	.064	54	.160	54	.269	63	.088	47
1971	.129	12	238	.062	53	.117	78	.217	43	.108	64
1972	.136	12	180	.062	37	.123	48	.224	44	.139	51
1973	.154	12	189	.070	43	.127	33	.296	40	.140	73
1974	.130	12	173	.064	47	.120	47	.250	17	.109	62
1975	.180	12	127	.081	34	.158	32	.278	32	.120	29
1976	.152	10	97	.056	25	.086	9	.298	23	.107	40
1977	.084	1	16	.084	16	****	0	****	0	****	0

SITE: BISMARCK, NORTH DAKOTA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1973	.066	11	284	.043	46	.084	71	.089	115	.042	52
1974	.058	12	247	.028	27	.061	31	.088	90	.059	99
1975	.090	12	282	.047	63	.103	52	.133	103	.075	64
1976	.072	12	326	.041	64	.110	90	.092	84	.053	88
1977	.037	1	3	.037	3	****	0	****	0	****	0

SITE: COLUMBUS, OHIO

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.120	11	102	.079	13	.116	28	.193	35	.118	26
1968	.192	5	46	.065	2	****	0	.141	25	.329	19

SITE: CINCINNATI, OHIO GEST ST

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.147	11	349	.103	35	.161	111	.214	84	.118	119
1968	.118	1	15	.118	15	****	0	****	0	****	0

SITE: CINCINNATI, OHIO

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.129	11	509	.102	81	.125	116	.187	158	.114	154
1968	.133	6	183	.086	27	****	0	.207	58	.101	98
1969	.114	7	198	.064	67	.161	109	.147	22	****	0

SITE: TOLEDO, OHIO

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.129	9	208	****	0	.136	54	.158	95	.108	59
1968	.098	6	132	.088	9	****	0	.130	76	.091	47
1969	.103	12	294	.095	44	.121	91	.142	92	.075	67
1970	.094	12	296	.062	47	.086	91	.137	128	.091	30
1971	.118	12	305	.054	40	.167	101	.175	102	.076	62
1972	.097	12	235	.045	37	.113	89	.161	59	.078	50
1973	.110	12	278	.050	51	.085	52	.190	98	.128	77
1974	.106	12	229	.060	38	.084	58	.188	73	.094	60
1975	.117	12	195	.089	25	.121	53	.172	67	.091	50
1976	.113	12	222	.077	34	.123	71	.171	65	.086	52
1977	.050	1	14	.050	14	****	0	****	0	****	0

SITE: YOUNGSTOWN, OHIO

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.139	11	365	.097	48	.125	110	.224	112	.105	95
1968	.123	6	201	.065	13	****	0	.174	88	.120	100
1969	.112	12	361	.065	56	.114	118	.167	99	.102	88
1970	.142	12	327	.079	41	.145	94	.225	115	.131	77
1971	.134	12	348	.107	41	.127	92	.185	118	.109	97
1972	.114	12	180	.063	48	.095	85	.152	31	.185	16
1973	.141	11	102	.074	21	.097	20	.269	37	.114	24
1974	.123	12	111	.083	18	.118	32	.200	33	.097	28
1975	.145	12	115	.092	11	.165	23	.205	46	.105	35
1976	.124	11	107	.088	8	.128	42	.169	35	.114	22
1977	.083	1	6	.083	6	****	0	****	0	****	0

SITE: PENDLETON, OREGON

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1972	.054	12	381	.028	28	.075	85	.063	165	.052	103
1973	.059	12	369	.036	52	.069	100	.084	148	.055	69
1974	.052	12	251	.032	19	.060	36	.052	123	.061	73
1975	.071	11	182	.045	11	.094	38	.082	77	.071	56
1976	.067	8	113	.022	1	.083	22	.070	30	.073	60
1977	.036	1	5	.036	5	****	0	****	0	****	0

SITE: PHILADELPHIA, PENNSYLVAN

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.204	10	254	.144	7	.168	48	.306	91	.160	108
1968	.247	6	221	.101	32	****	0	.344	88	.244	101
1969	.268	12	307	.168	53	.244	92	.464	66	.217	96
1970	.400	11	163	.221	37	.455	31	.514	49	.403	46
1971	.334	2	22	****	0	.345	22	****	0	****	0

SITE: HURON, SOUTH DAKOTA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.070	11	539	.048	54	.091	106	.078	228	.056	151
1968	.055	6	291	.031	36	****	0	.079	134	.048	121
1969	.069	12	489	.044	67	.094	139	.091	174	.050	109
1970	.071	12	505	.037	68	.082	123	.087	206	.086	108
1971	.091	12	414	.054	93	.121	92	.113	137	.077	92
1972	.064	12	193	.041	59	.079	36	.081	53	.059	45
1973	.074	11	144	.060	43	.076	40	.076	30	.055	31
1974	.082	12	193	.090	53	.075	31	.096	63	.070	46
1975	.094	11	185	.070	49	.097	19	.133	64	.086	53
1976	.078	5	60	.086	18	****	0	.110	19	.055	23

SITE: MEMPHIS, TENNESSEE

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.149	11	100	.099	22	.179	23	.205	18	.112	37
1968	.120	6	76	.071	8	****	0	.126	29	.116	39
1969	.117	12	161	.110	31	.133	29	.156	57	.086	44
1970	.139	12	128	.077	28	.141	33	.197	42	.127	25
1971	.204	12	210	.105	24	.181	51	.331	74	.203	61
1972	.350	12	156	.176	33	.304	51	.460	58	.476	14
1973	.198	6	75	.338	27	****	0	.143	3	.126	45
1974	.133	10	71	.115	5	.096	18	.171	11	.087	37
1975	.146	11	45	.077	16	.169	4	.275	10	.123	15
1976	.151	12	85	.077	19	.102	15	.326	27	.102	24
1977	.063	1	6	.063	6	****	0	****	0	****	0

SITE: OAK RIDGE, TENNESSEE

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.154	11	203	.101	34	.140	58	.219	52	.133	59
1968	.145	6	76	.110	5	****	0	.212	34	.110	37
1969	.148	12	160	.096	30	.149	50	.254	39	.107	41
1970	.149	8	124	.087	39	.122	63	.284	22	****	0
1971	.198	4	58	****	0	****	0	.295	11	.167	47
1972	.158	12	186	.094	32	.155	47	.241	53	.169	54
1973	.175	12	248	.062	49	.118	50	.348	76	.200	73
1974	.167	12	190	.073	53	.139	54	.310	28	.108	55
1975	.209	12	140	.099	22	.200	24	.387	47	.177	47
1976	.204	10	174	.085	16	.146	27	.334	76	.160	55
1977	.085	1	13	.085	13	****	0	****	0	****	0

SITE: GRAND PRAIRIE, TEXAS

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1971	.119	7	272	****	0	.147	78	.157	89	.074	105
1972	.096	12	429	.047	74	.112	107	.132	134	.092	114
1973	.089	12	393	.054	68	.091	95	.122	132	.083	98
1974	.081	12	298	.048	83	.105	93	.103	89	.075	33
1975	.142	11	193	.057	15	.136	20	.256	37	.165	121
1976	.181	12	508	.089	89	.205	109	.264	200	.192	110
1977	.070	1	29	.070	29	****	0	****	0	****	0

SITE: STERLING, VIRGINIA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.110	4	34	.104	22	.113	12	****	0	****	0
1971	.171	6	55	.066	3	.113	42	.221	10	****	0

SITE: REDMOND, WASHINGTON

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1971	.203	8	100	.098	2	.239	28	.252	52	.160	18

SITE: SEATTLE, WASHINGTON

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1968	.122	1	13	****	0	****	0	****	0	.122	13
1969	.149	11	102	.168	12	.128	32	.187	25	.120	33
1970	.129	7	50	.138	22	.140	22	.097	6	****	0

SITE: ELKINS, WEST VIRGINIA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.156	11	373	.084	51	.148	92	.247	101	.130	129
1968	.147	6	183	.101	23	****	0	.199	63	.133	97
1969	.182	12	330	.107	50	.202	125	.283	81	.135	74
1970	.192	12	202	.122	33	.186	54	.308	38	.192	77
1971	.176	12	239	.099	53	.171	88	.268	57	.176	41
1972	.116	11	130	.089	42	.155	41	.176	19	.065	28
1973	.143	11	68	.069	20	.110	13	.193	24	.218	11
1974	.148	6	16	.217	7	.123	9	****	0	****	0
1975	.038	1	1	.038	1	****	0	****	0	****	0

SITE: GREEN BAY, WISCONSIN

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.099	11	259	.055	40	.116	84	.127	81	.111	54
1968	.086	6	106	.052	14	****	0	.103	46	.088	46
1969	.094	12	230	.077	42	.119	80	.131	69	.065	39
1970	.101	12	204	.065	55	.118	50	.140	52	.077	47
1971	.080	12	261	.068	55	.099	66	.089	96	.069	44
1972	.079	12	224	.052	45	.113	67	.105	64	.060	48
1973	.081	12	204	.047	38	.087	49	.120	64	.068	53
1974	.082	12	167	.047	41	.090	27	.102	54	.088	45
1975	.101	12	202	.067	32	.117	61	.151	48	.071	61
1976	.102	12	254	.091	31	.109	61	.130	90	.087	72
1977	.055	1	14	.055	14	****	0	****	0	****	0

SITE: SAN RAFAEL, CALIFORNIA

YEAR	ANNUAL AVERAGE	NUMBER OF MOS	NUMBER OF OBS	WINTER AVERAGE	NUMBER OF OBS	SPRING AVERAGE	NUMBER OF OBS	SUMMER AVERAGE	NUMBER OF OBS	FALL AVERAGE	NUMBER OF OBS
1967	.126	8	347	****	0	.127	62	.131	144	.122	141
1968	.086	1	21	.086	21	****	0	****	0	****	0